Hadronic Two-body decays of B and D mesons at CDF .

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Outlines

- CP Violation and $B^0_{(s)} \to h^+h'^-$ decays.
- Analysis overview: BR and A_{CP} of $B^0_{(s)} \to h^+h'^-$ decays on $1fb^{-1}$.
  - Results.
- From $B^0_{(s)} \to h^+h'^-$ to $D^0 \to h^+h'^-$ decays at CDF:
  - World's largest data samples.
  - Enormous potentialities in charm physics.
  - Measurement of the time-integrated CP asymmetry in the Cabibbo Suppressed $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ decays.
- Conclusions and prospects

CP Violation (CPV)

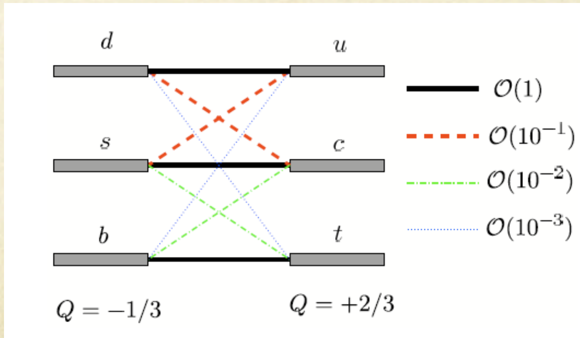
- The non-invariance of the weak interactions with respect to the combined charge-conjugation (C) and parity (P) dates back to year 1964. Measurement of $\varepsilon_K \approx 10^{-3}$ was the first manifestation of a **"CP violation in mixing"** .
- Ever since CPV crucial goal in HEP.
  - Essential to understand and test the SM.
  - To probe physics beyond the SM.
  - To shed light on cosmology issues. CPV present in the SM seems to be small to generate the observed baryonic asymmetry $O(10^{-10})$.
  - ....

Cabibbo-Kobayashi-Maskawa Matrix

- CPV originates from the charged-current interactions of quarks. CKM matrix connects the electroweak states of the down, strange and bottom quarks with their mass eigenstates.
  - N=3 quark generations ⇒ 3 Euler angles and <u>one complex phase</u>
  - Complex phase allows to accommodate CPV in the SM.

Electroweak eigenstates | V_{CKM} (unitary) | Mass flavor eigenstates

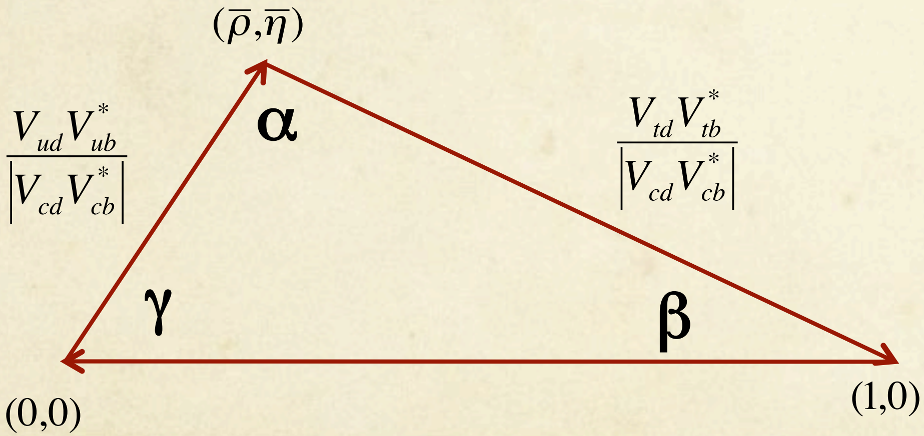
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

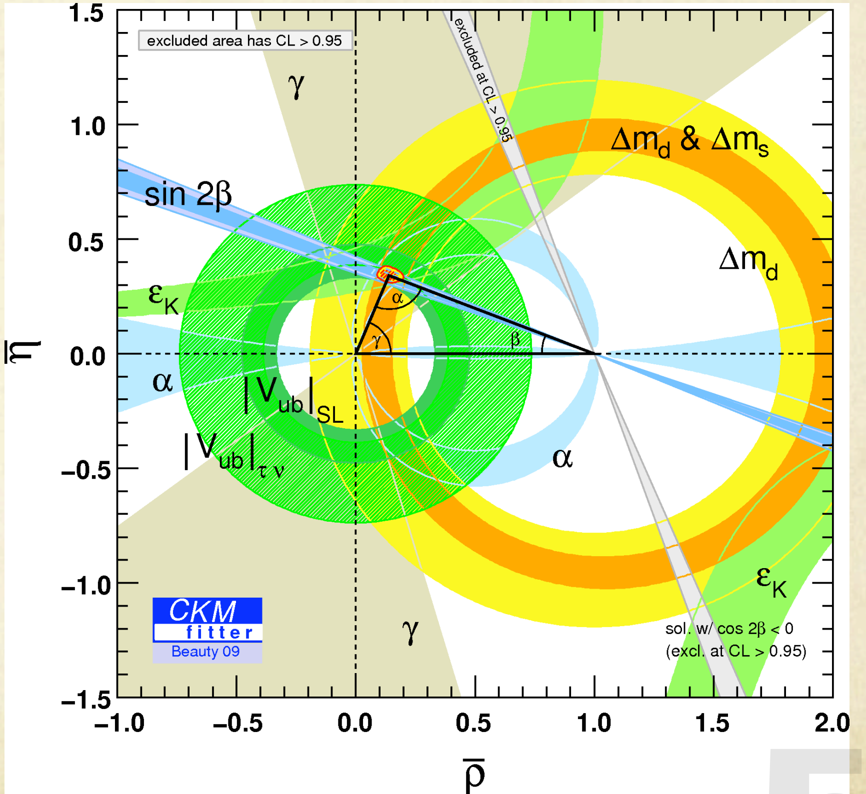


Unitarity Triangle (UT)

Since the CKM matrix is unitary the CP violation has to be proportional to the area of the Unitarity Triangle. A non-squashed triangle in the complex plane means CP violation.

CP violation $\Rightarrow \alpha,\beta,\gamma \neq 0$





$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

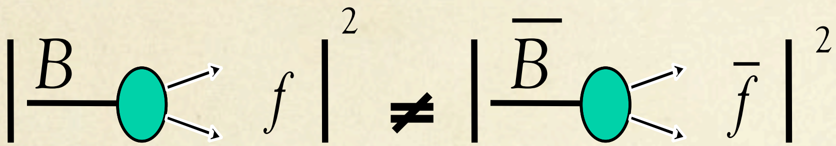
CP Violation observables

- CPV in mixing (or indirect CP violation)
- CPV in decay (or direct CP violation)
  - In 1999 NA48 and KTeV measured a non vanishing value for $Re(\varepsilon'_K/\varepsilon_K)$.
  - in 2004, BaBar and Belle announced direct CP violation in the $B^0 \to K^+\pi^-$,
- CPV in the interference between a decay without mixing, and with mixing.
  - In 2001 Babar and Belle measured CP-violating effect in $B^0 \to J/\psi K_s$ mode.

Main part focused on the direct CPV (time integrated CPV) in the system of two body charmless decays of neutral B (D) mesons.

$$\mathcal{A}_{\rm CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} = \frac{|A(\bar{B} \to \bar{f})|^2 - |A(B \to f)|^2}{|A(\bar{B} \to \bar{f})|^2 + |A(B \to f)|^2}$$

Direct CP Violation in the decay



$A = \langle f \mid H \mid B \rangle \qquad \bar{A} = \langle \bar{f} \mid H \mid \bar{B} \rangle$

$\bar{A} / A \neq 1 \Leftrightarrow$ direct CPV

$$\begin{aligned} \overline{A}(\bar{B} \to \bar{f}) &= e^{+i\varphi_1}|A_1|e^{i\delta_1} + e^{+i\varphi_2}|A_2|e^{i\delta_2} \\ A(B \to f) &= e^{-i\varphi_1}|A_1|e^{i\delta_1} + e^{-i\varphi_2}|A_2|e^{i\delta_2} \end{aligned}$$

(Requires interference of two amplitudes)

The CP-violating phases φ originate from CKM factors, and the CP-conserving phase "strong" amplitudes $|A|e^{i\delta}$ involve the strong interaction. For a non-vanishing value we need simultaneously a non trivial weak phase difference φ_1-φ_2 and a non-trivial strong phase difference δ_1-δ_2.

φ_1-φ_2= angle γ in the $B^0 \to K^+\pi^-$

$$\mathcal{A}_{\mathrm{CP}} = -\frac{2|A_1||A_2|\sin(\delta_1 - \delta_2)\sin(\varphi_1 - \varphi_2)}{|A_1|^2 + 2|A_1||A_2|\cos(\delta_1 - \delta_2)\cos(\varphi_1 - \varphi_2) + |A_2|^2}.$$

Hard to predict from the theory (due to $\delta_1$and δ_2 strong phases)

CP Violation in $B^0 \rightarrow K^+\pi^-$

First direct CPV in the B-mesons system. First evidence at ICHEP 2004 BaBar (4.2σ) and Belle(3.9σ) . Today established >5σ, latest measurements are:

$$BaBar(384\,MB\bar{B}) \Rightarrow A_{CP}(B^0 \rightarrow K^-\pi^+) = -0.107 \pm 0.016(stat)^{+0.006}_{-0.004}(syst)$$

$$Belle(532\,MB\bar{B}) \Rightarrow A_{CP}(B^0 \rightarrow K^-\pi^+) = -0.094 \pm 0.018(stat) \pm 0.008(syst)$$

HFAG09

U-spin symmetry (spect. quark) predicts: $A_{CP}(B^0 \rightarrow K^+\pi^-) \approx A_{CP}(B^+ \rightarrow K^+\pi^0)$. But experimental data do not confirm this expectation.

$$A_{CP}(B^+ \rightarrow K^+\pi^0) = +0.050 \pm 0.025$$

HFAG09

Possible hint of NP? 4th generation?

Although large amount of experimental data, still now large theoretical uncertainties. D^0-mixing parameters O(1%), sin(2βs), $A_{FB}(b \rightarrow sll)$ could be hints in the same direction. Can more data help? Can B_s modes help?

CP Violation in $B^0_s \to K^- \pi^+$

$B^0_s \to K^- \pi^+$ decay offers a unique opportunity of checking for the SM origin of direct CP violation. Proposed by Gronau *[Phys.Rev. B482, 71(2000)],* later shown to hold under much weaker assumptions by Lipkin *[Phys. Lett. B621,126, (2005)].* (CPT, SM, $m_{Bd} \approx m_{Bs}$, $f_\pi \approx f_K$,...)

$$\Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-) = \Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-),$$
$$\mathcal{A}_{\rm CP}(B^0_s \to K^-\pi^+) = -\mathcal{A}_{\rm CP}(B^0 \to K^+\pi^-) \times \frac{\mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(B^0_s \to K^-\pi^+)} \times \frac{\tau(B^0_s)}{\tau(B^0)}.$$

Low BR($B^0_s \to K^+\pi^-$) implies large asymmetry. Large expected asymmetry ≈ +40-50% (Interesting case of large DCPV predicted under SM).

Any significant disagreement should be strong indication of NP.

$B^0_s \to K^- \pi^+$ is still unobserved

Currently accessible only to hadronic machines, entangled with other $B^0_{(s)} \to h'^+ h^-$

Experimental status $B^0_{(s)} \to h^+ h'^-$

BR·10^{-6}

From HFAG 2007

	BABAR	Belle	CLEO	CDF
$\mathcal{B}(B^0 \to \pi^+\pi^-)$	$5.5 \pm 0.4 \pm 0.3$	$5.1 \pm 0.2 \pm 0.2$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	$3.9 \pm 1.0 \pm 0.6$
$\mathcal{B}(B^0 \to K^+\pi^-)$	$19.1 \pm 0.6 \pm 0.6$	$19.9 \pm 0.4 \pm 0.8$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	–
$\mathcal{B}(B^0 \to K^+K^-)$	< 0.5 @ 90%CL	< 0.41 @ 90%CL	< 0.8 @ 90%CL	< 1.8 @ 90%CL
$\mathcal{B}(B^0_s \to \pi^+\pi^-)$	–	–	–	< 1.7 @ 90%CL
$\mathcal{B}(B^0_s \to K^-\pi^+)$	–	–	–	< 5.6 @ 90%CL
$\mathcal{B}(B^0_s \to K^+K^-)$	–	–	–	$33 \pm 6 \pm 7$

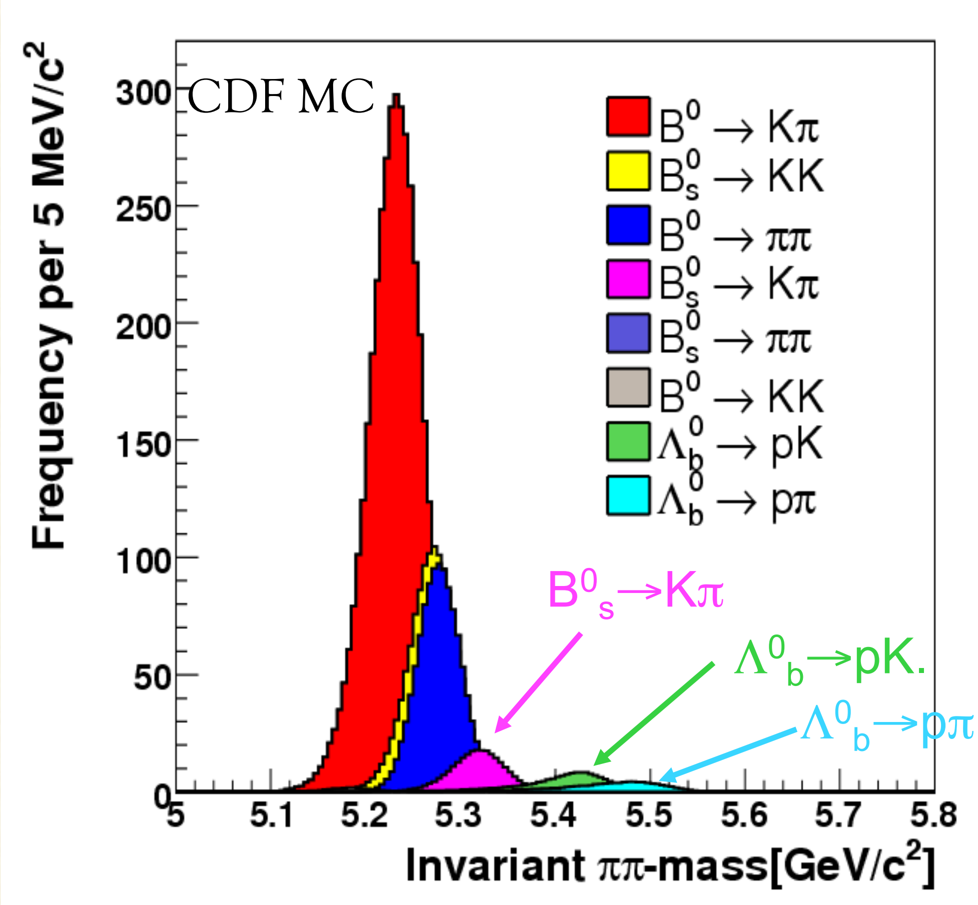
First observation

From previous published version of this analysis with L_{int} =180 pb^{-1}. [Phys.Rev.Lett. 97, 211802 (2006)] .

"Large modes" already observed: $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$, $B^0_s \to K^+K^-$.

"Rare modes" still unobserved: $B^0_s \to \pi^+\pi^-$, $B^0_s \to K^-\pi^+$, $B^0 \to K^+K^-$.

$B^0_{(s)} \rightarrow h^+h'^-$ at CDF



Despite good mass resolution (≅22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)

Note that the use of a single mass assignment ($\pi\pi$) causes overlap even with perfect resolution.

Each mode is a background for others. i.e. $\Lambda^0_b \rightarrow p\pi/pK$ are "backgrounds" of $B^0_s \rightarrow K\pi$ "signal". Also the large modes are background for $B^0_s \rightarrow K\pi$ "signal".

Need to determine signal composition with a **Likelihood fit**, combining information from **kinematics** (mass and momenta) and **particle ID** (dE/dx).

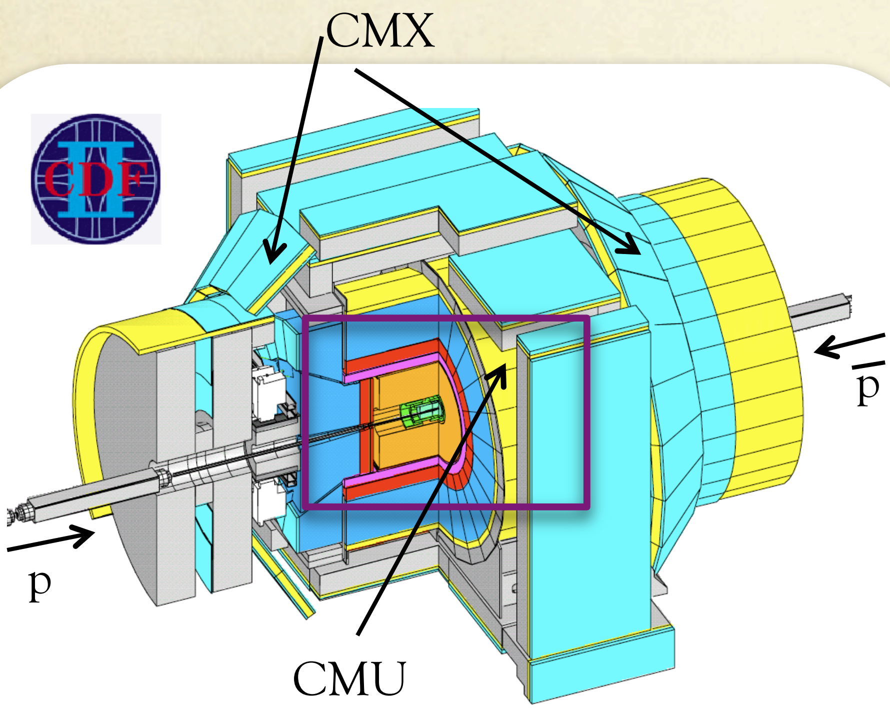
$B^0_{(s)} \rightarrow h^+h'^-$ at CDF (cont'd)

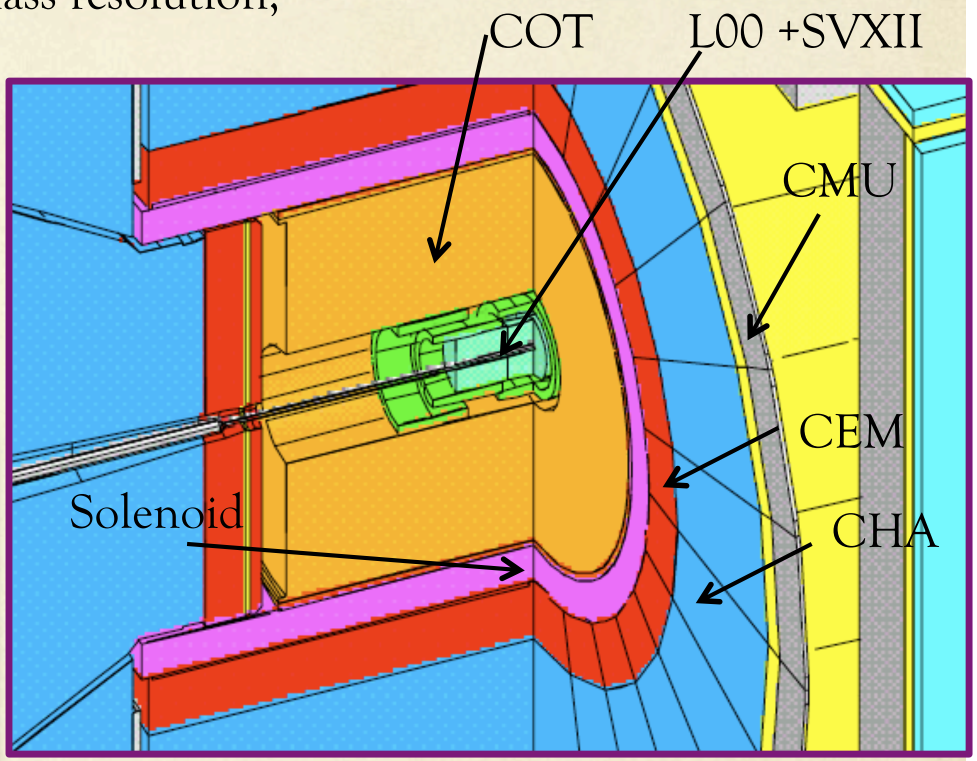
- Amazing possibilities for probing into dynamics of all charmless charged decays:
  - CPV and BR of $B^0 \rightarrow K\pi$, $B^0_s \rightarrow K\pi$.
  - More stringent limit (or possible observation) of rare modes
    - Annihilation modes $B^0 \rightarrow KK$ and $B^0_s \rightarrow \pi\pi$ (hard to predict !)
  - Precision BR for $B^0_s \rightarrow KK$, $B^0 \rightarrow \pi\pi$.
  - BR and CPV of charmless two-body baryonic modes.
- Several strategies to extract CKM matrix elements (i.e. γ angle):
  - exploit flavor symmetries (SU(3), U-spin) to constrain (or partially cancel out) hadronic uncertainties from penguin diagrams.
  - Measurement of SU(3) breaking size.
- Program complementary to other experiments.

Very rich phenomenology but challenging measurement.

CDFII detector

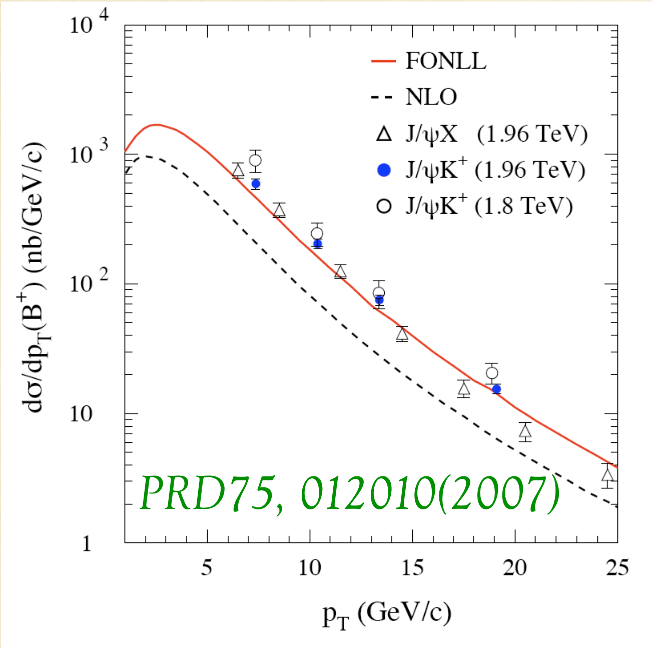
Central tracking includes silicon vertex detector surrounded by drift chamber;
p_T resolution $dp_T/p_T = 0.0015\ p_T$ $\rightarrow$ excellent mass resolution,
Particle identification: dE/dX and TOF;
Good electron and muon identification
by calorimeters and muon chambers.

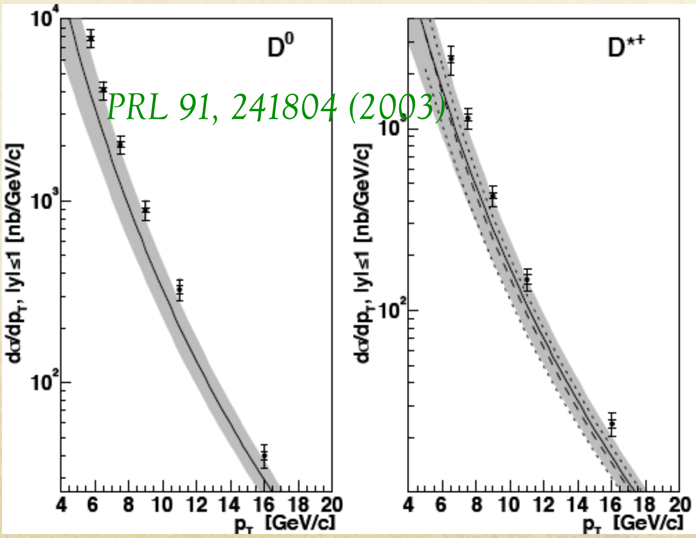




CMU ($|\eta|<0.6$, pt>1.4GeV/c) 4 layers of planar drift chambers
CMX($0.6<|\eta|<1$, pt>2GeV/c) conical sections of drift tubes

$\bar{p}p$ collisions: the good



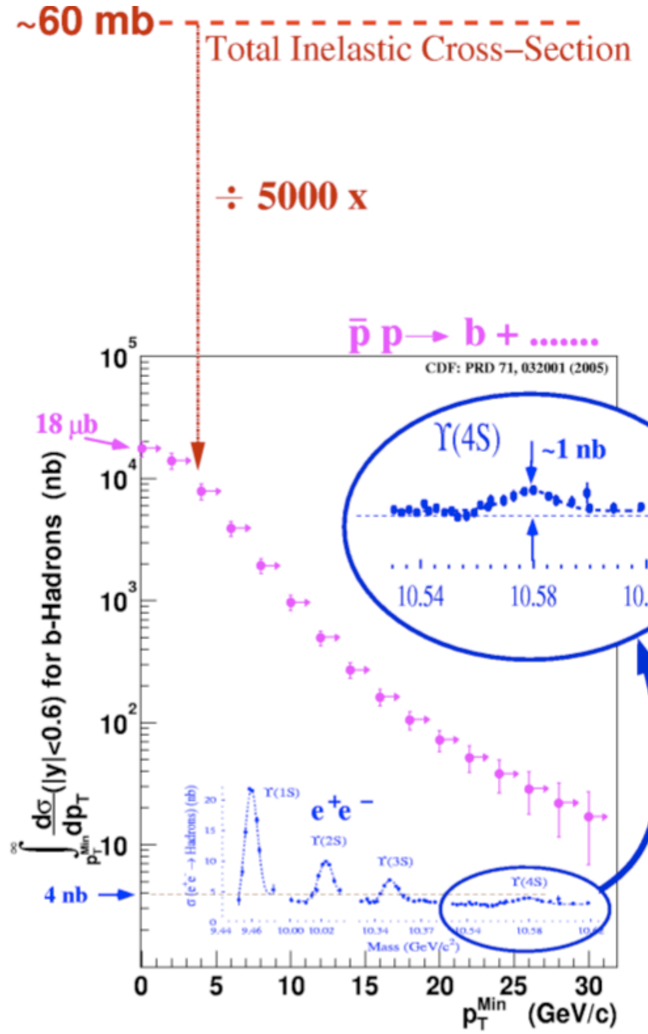


Strong, incoherent production of all b(c)-hadrons.
Some examples:
$\sigma(B^+, p_T > 6\mathrm{GeV}/c, |y|<1) = 2.65 \pm 0.24\ \mu b$
PRD 75 012010 (2007)
$\sigma(D^0, p_T > 5.5\mathrm{GeV}/c, |y|<1) = 13.3 \pm 2.5\ \mu b$
PRL 91, 241804 (2003)

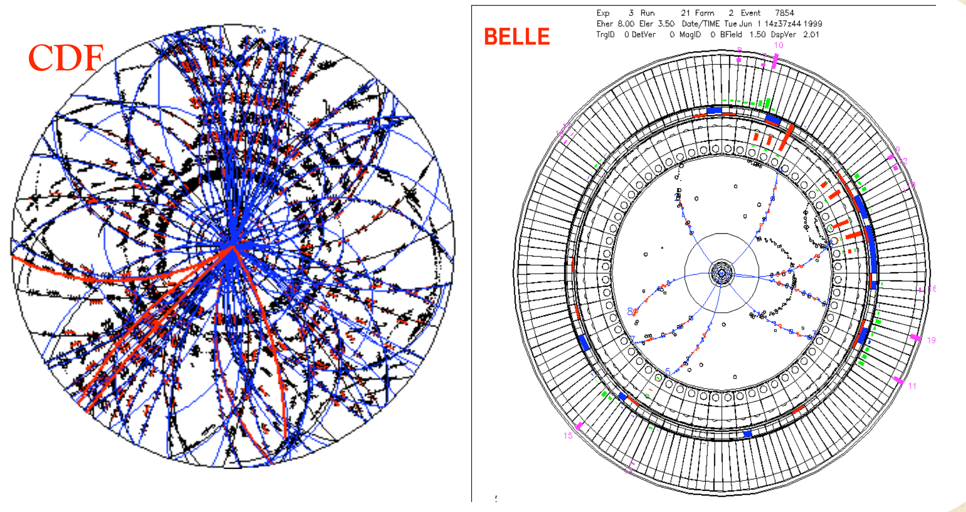
"More than" 1000 B mesons and 2000 D^0 per second within acceptance at $L=150 \times 10^{32}\ cm^{-2}s^{-1}$.
Corresponding to 3×10^{10} B mesons and 6×10^{10} D^0 mesons produced in 1 year of data taking.

All b and c hadrons (B^0,$B^+B^0_s$,L^0_b,D^0,D^+D^{*+},D_s,etc) are produced over the whole momentum spectrum.

$\bar{p}p$ collisions: the ugly



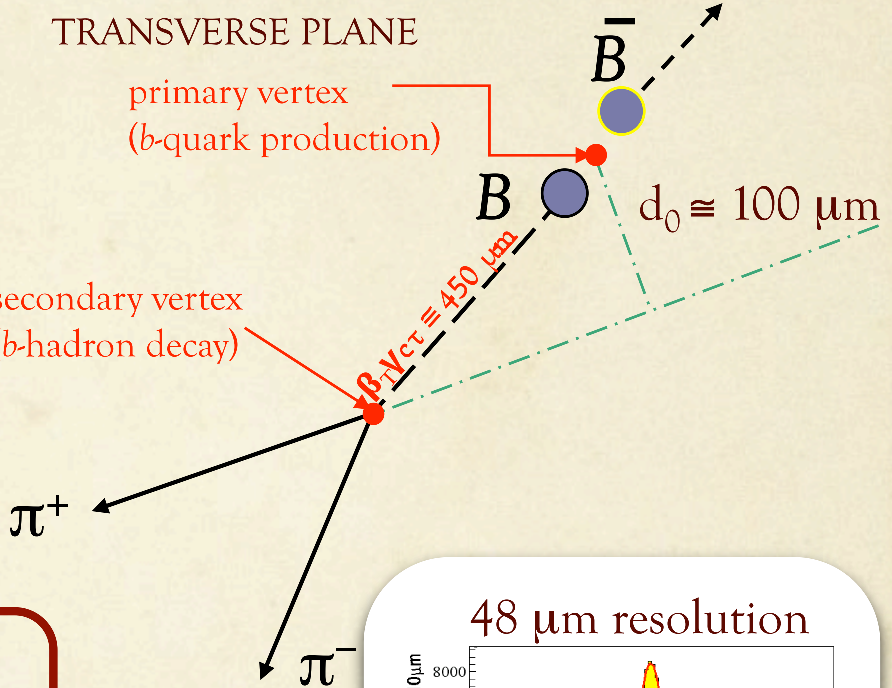
Backgrounds are 5×10^3 larger than interesting processes with a b or c hadrons.
Kaons and pions of final states entirely similar to the generic QCD background.
Very messy environment.



Crucial role: highly selective trigger.

Hadronic trigger

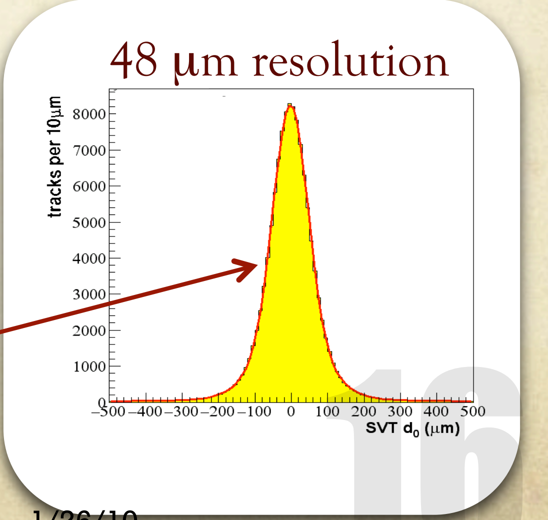
1.5(0.5) ps lifetime of *b*(*c*)-hadrons: a powerful signature. Sufficiently boosted *B*(*D*) fly a path resolvable with vertex detectors.



In Run I, this was exploited offline,
in Run II in the trigger
An experimental challenge that requires:

(1) high resolution vertex detector;
(2) read out silicon (212,000 channels in r-ϕ);
(3) do pattern recognition and track fitting.

within 25 μs



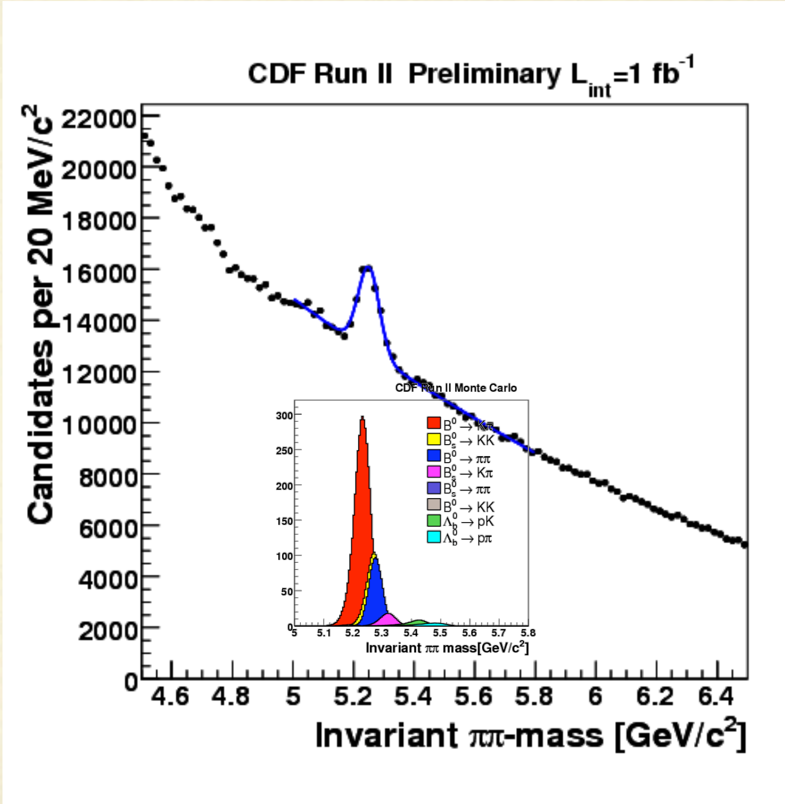
Include beam spot size ~30μm

It all begins in the trigger

- Two oppositely-charged tracks (i.e. *B* candidate) from a long-lived decay:
  - track's impact parameter;
  - *B* transverse decay length;
- *B* candidate pointing back to primary vertex:
  - impact parameter of the *B*;
- Reject light-quark background from jets:
  - transverse opening angle;
  - p_{T1} and p_{T2} ;
  - $p_{T1}+p_{T2}$.

Variables used for further analysis:
Isolation: I(B) (rejects light quark backg.)
3D vertex quality: $\chi^2_{3D}(B)$.

Signal (BR~10^{-5}) visible with just offline trigger cuts confirmation:

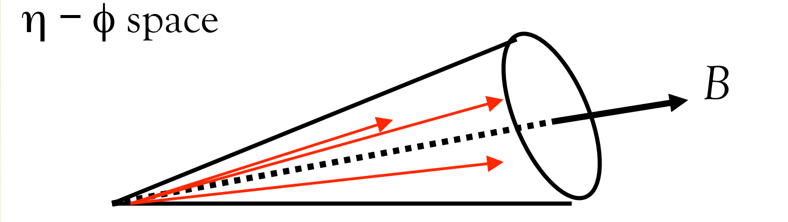


a bump of ~14500 events with S/B ≈ 0.2 (at peak) in $\pi\pi$-invariant mass

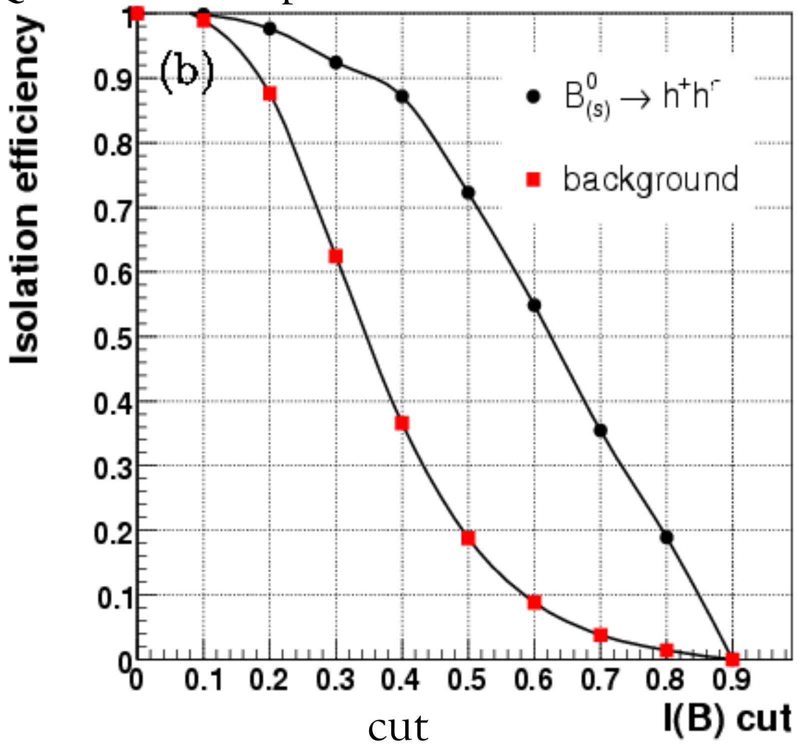
Isolation(B)

Fraction of p_T carried by the B candidate after fragmentation in a cone ($\eta - \phi$ space) with radius 1. High discrimination power signal vs backg.

$$I_{R=1}(B) = \frac{p_T(B)}{p_T(B) + \sum_i p_T(i)}$$



Qualitative shape from B→hh data



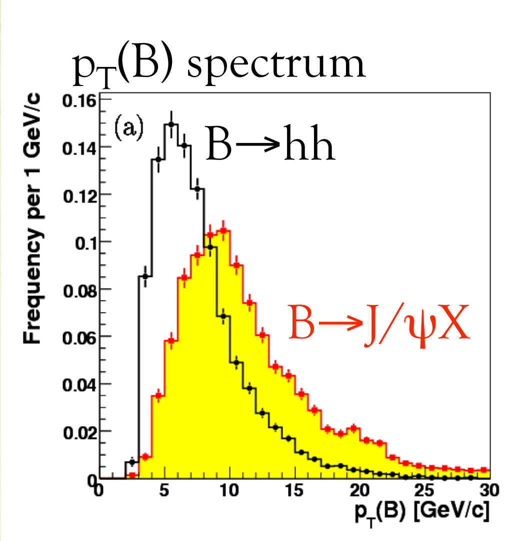
cut

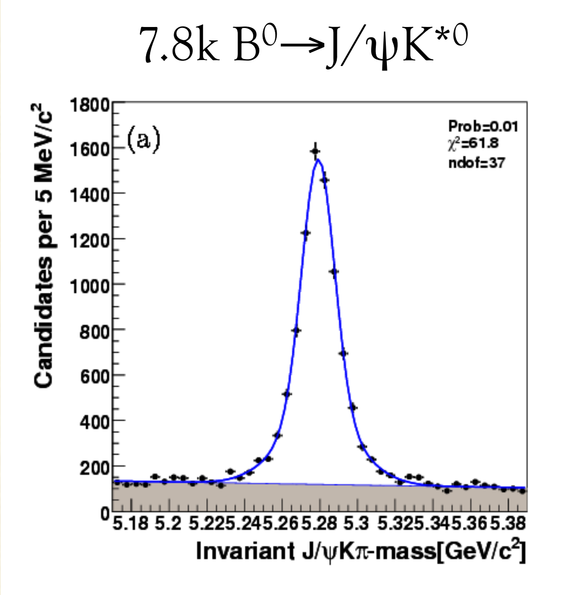
Isolation efficiency is p_T –dependent.
It may be different in B^0_s and B^0 order few%.
Monte Carlo not very reliable in reproducing fragmentation.

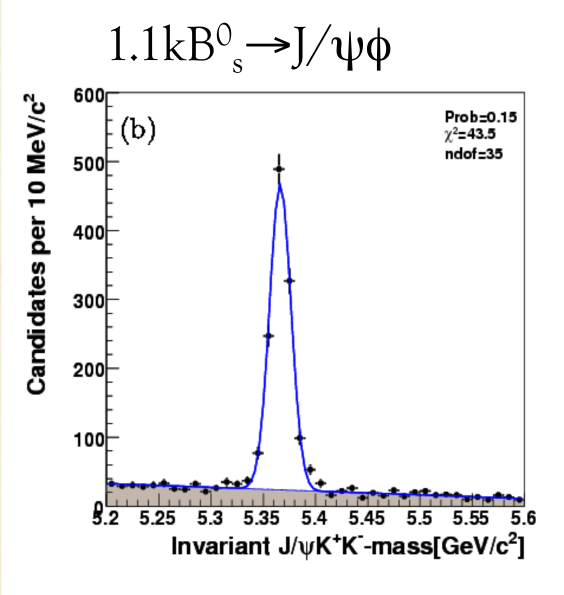
⇒ Measure efficiency on data.

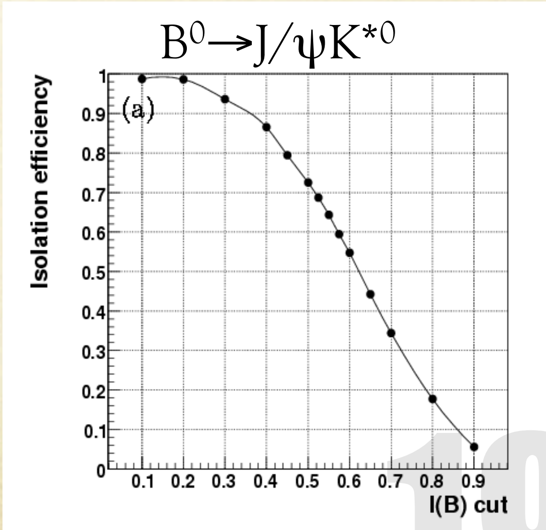
Isolation efficiency from B→J/ψX

Need low-p_T samples: low edge of p_T~ 2-3 GeV/c.
Simultaneous Maximum Likelihood fit (p_T -reweighted) of yields passing and failing the isolation cut in exclusive modes.







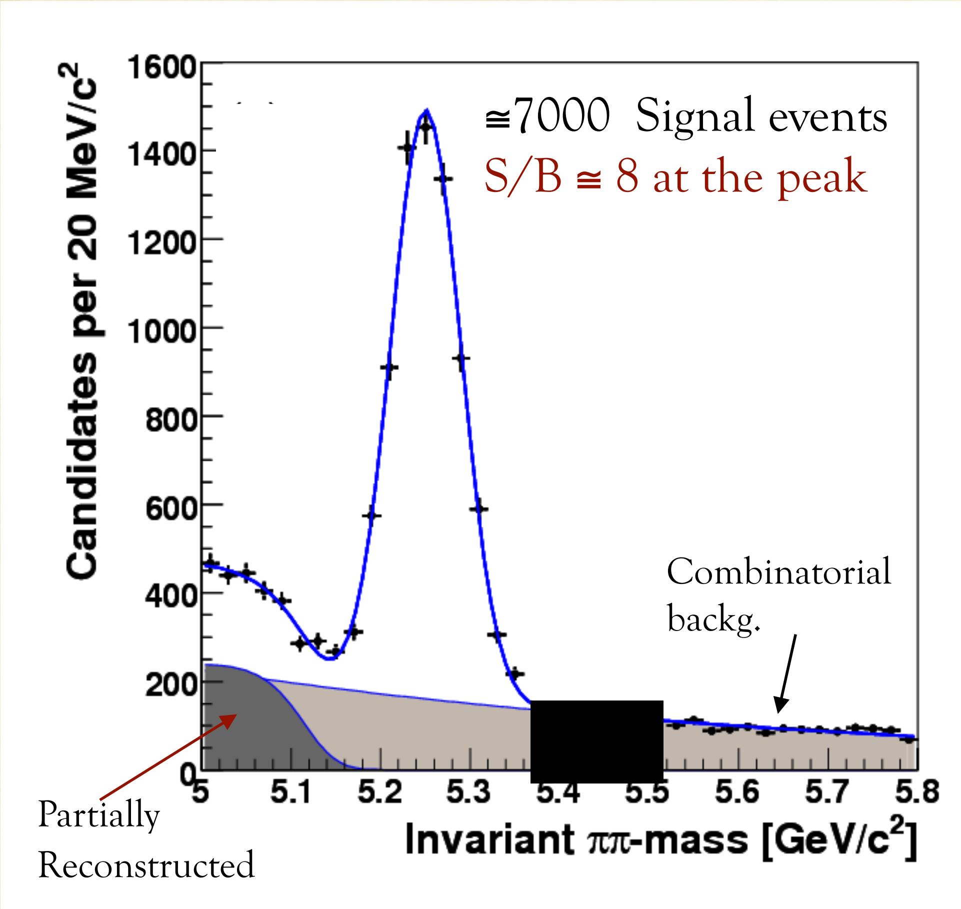


First evaluation at CDF ⇒

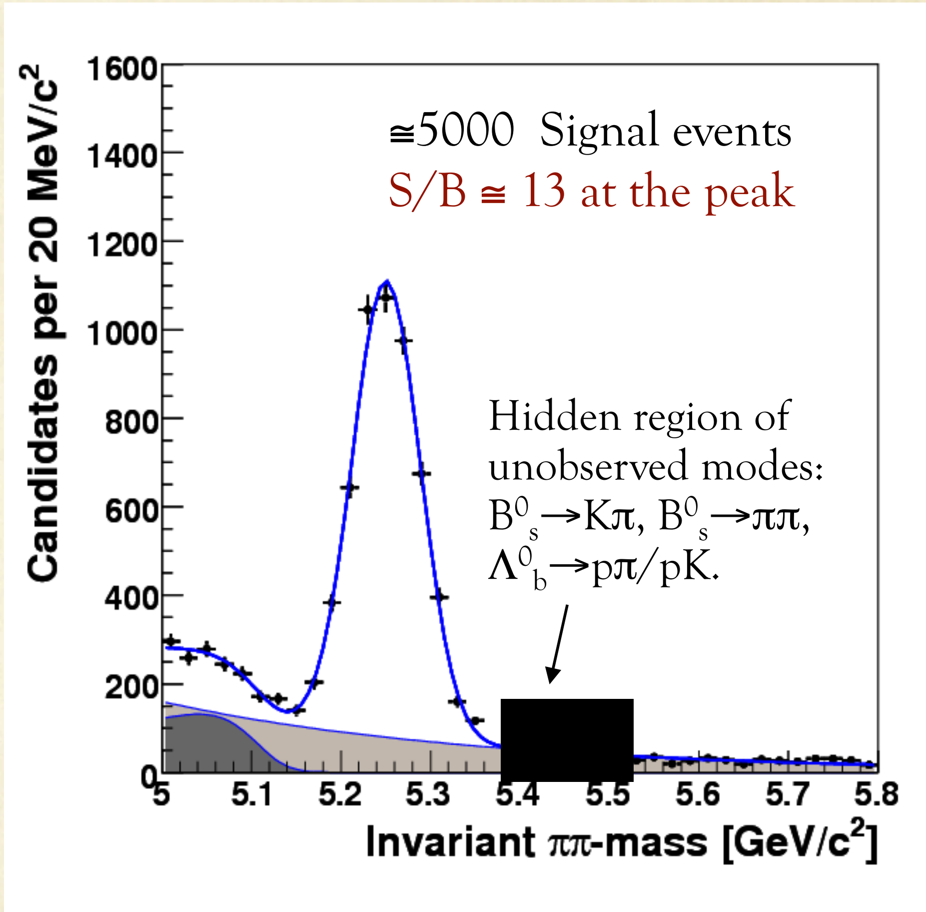
$$\frac{\varepsilon_{\rm iso}(B^0)}{\varepsilon_{\rm iso}(B^0_s)} = 1.000 \pm 0.028.$$

Data samples (L_{int} = 1fb^{-1})

Optimized for $A_{CP}(B^0 \rightarrow K^+\pi^-)$



Optimized for $B^0_s \rightarrow K^-\pi^+$ observation



Selection optimized to minimize the statistical uncertainty on the quantity one whishes to measure. For first time implemented in CDF and inherited in several other analyses. Details in *FERMILAB-THESIS-2007-57*.

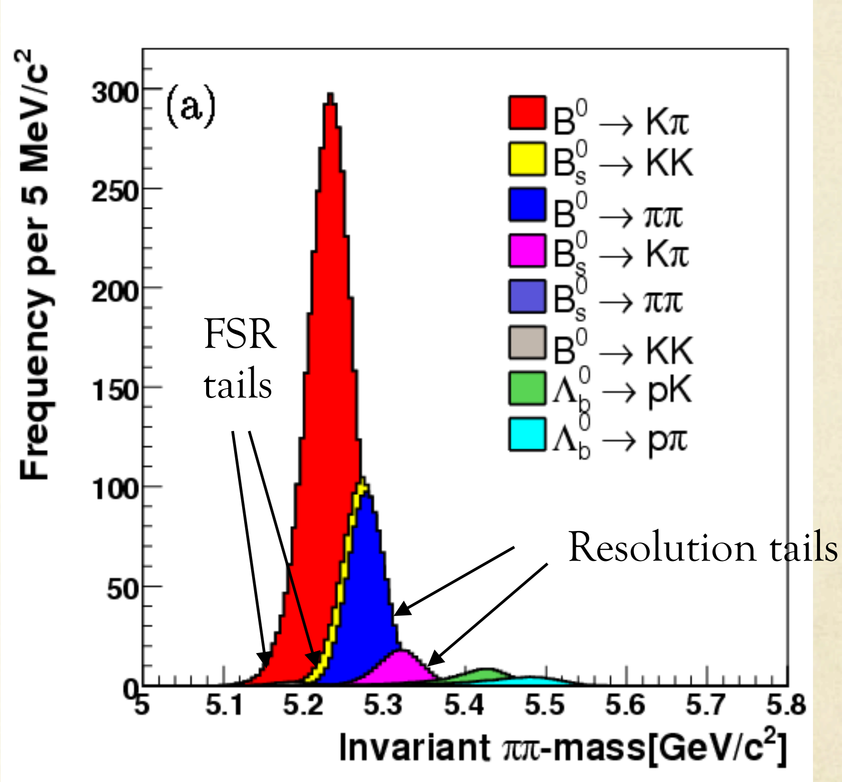
Separation handle 1:invariant mass

Different modes are somewhat separated in mass (~50 MeV between $B^0 \rightarrow K^+\pi^-$ and $B^0_s \rightarrow K^+K^-$)

However, results depend on assumed mass resolution and details of the line shape (rare modes confuse with the tails of larger modes).

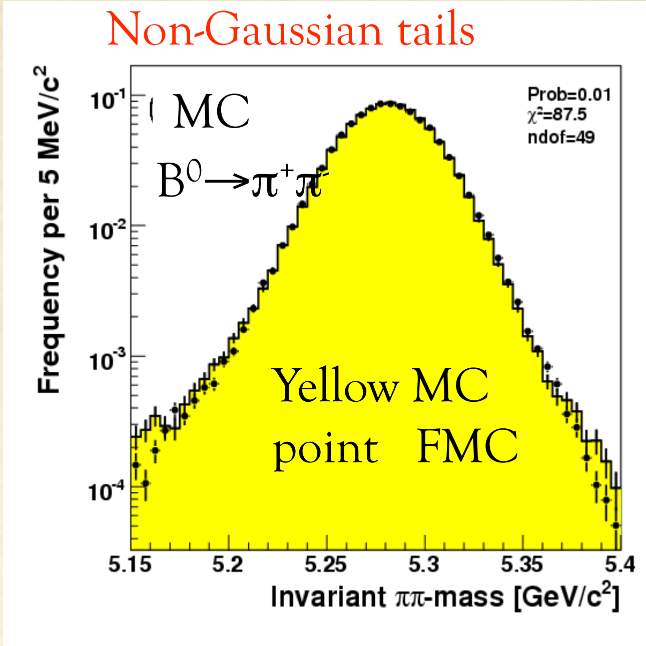
Need precise control of non-gaussian resolution tails and radiative effects

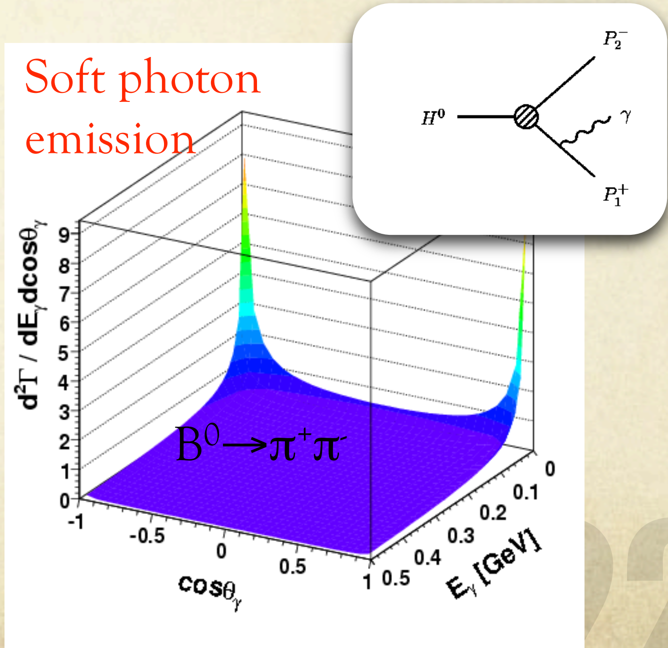
No previous analysis in CDF needed this precision ⇒First time.
MC does not reproduce accurately both effects, and never tested before.



Tails of mass resolution

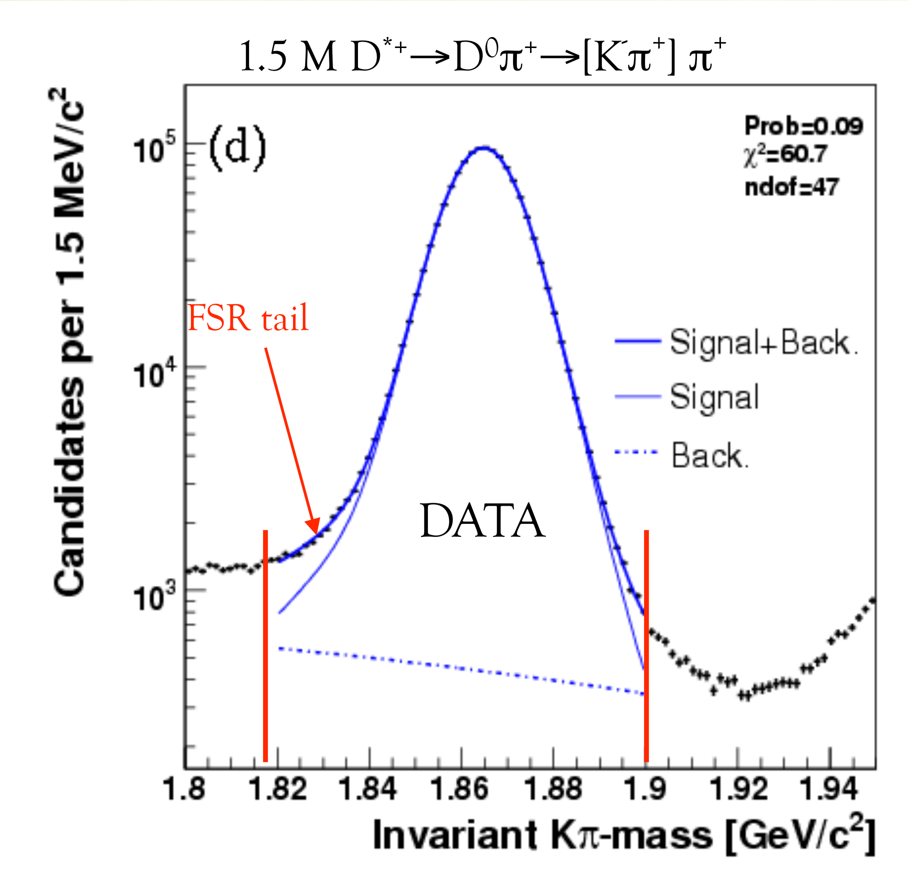
- Accurate parameterization of individual track parameters resolution functions (curvature, cot(θ),φ) as a function of curvature from full CDF MC (including non-gaussian tails)
- Parametric Fast Monte Carlo (FMC) to reproduce the mass line shape as a function of resolution functions.
- Add calculated QED radiation to the CDF simulation *[Baracchini,Isidori Phys.Lett B633,309-313(2006)]*
- Easy tuning with a reference peak.

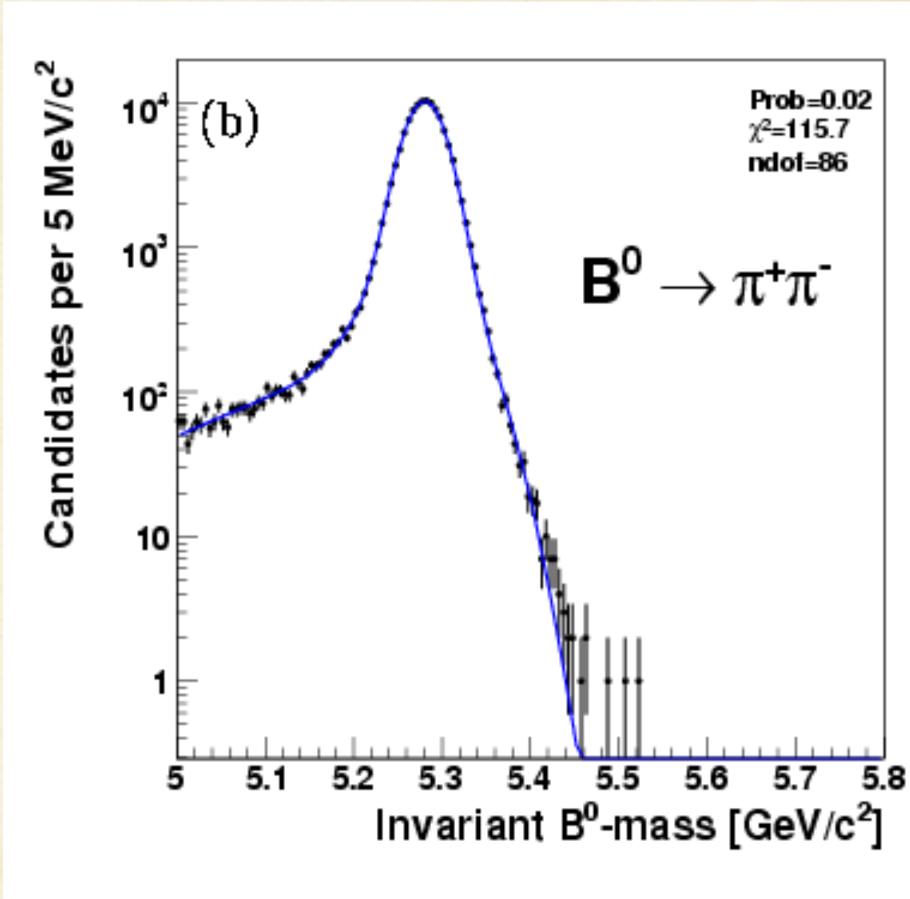




Comparison with real data
$D^0 \to K^- \pi^+$

$B \to hh$ templates





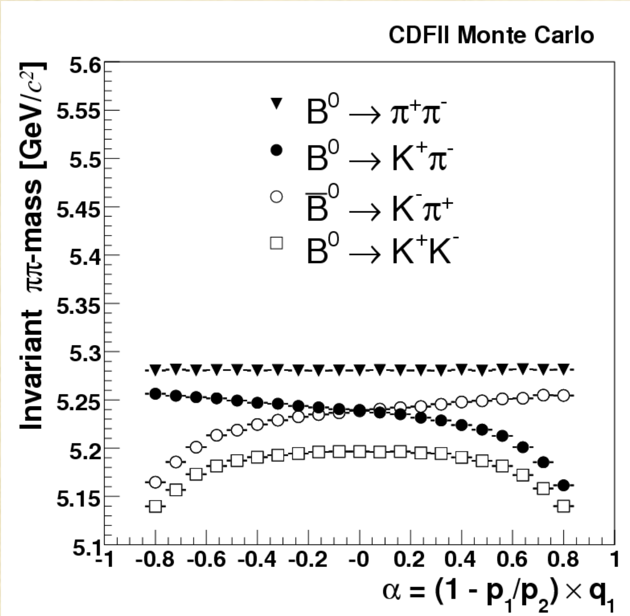
$\Rightarrow$ good match, no tuning necessary $\Rightarrow$ small systematics

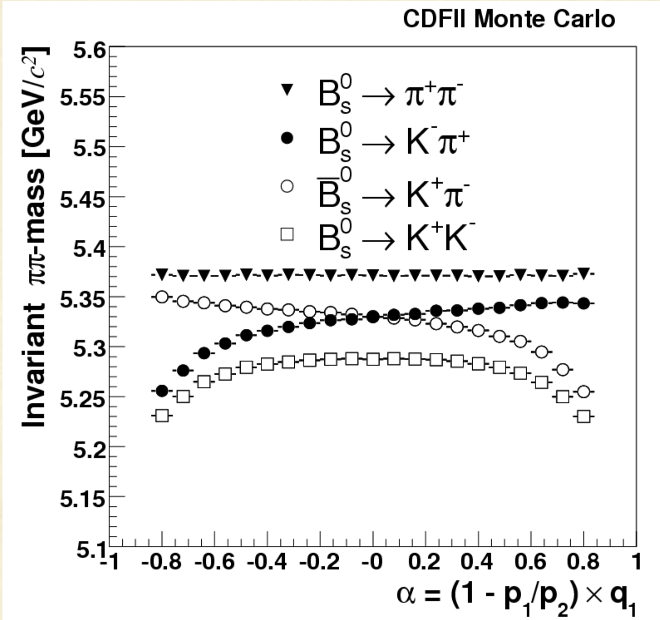
Generate $B \to hh$ templates and use them in the Likelihood fit.

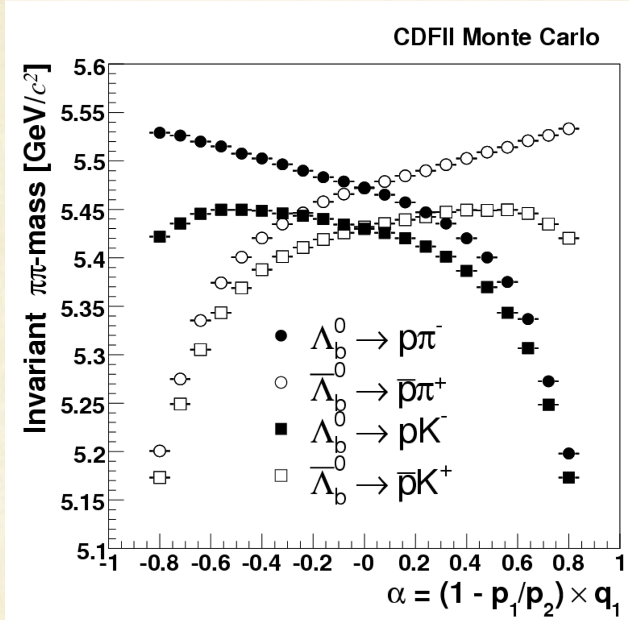
First in CDF and later used in other several CDF analyses.

Separation handle 2: track momenta

Exploit dependence between invariant mass
and momentum imbalance







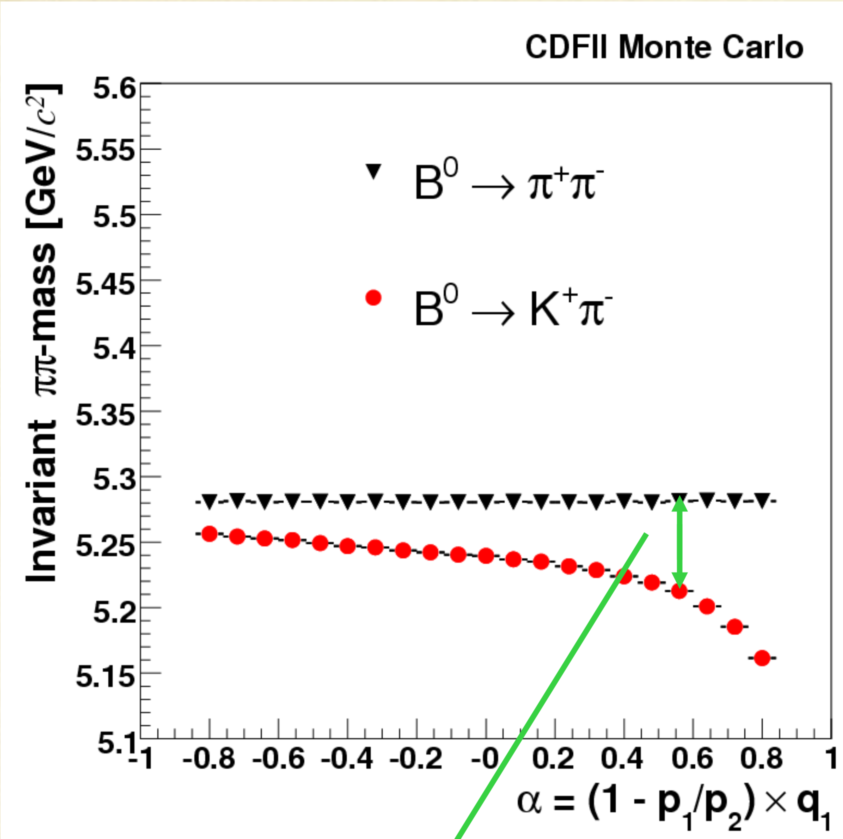
1) $m_{\pi\pi}$ invariant $\pi\pi$-mass

2) $\alpha = (1\text{-}p_{min}/p_{max})q_{min}$ signed p-imbalance

3) $p_{tot} = p_{min} + p_{max}$ scalar sum of 3-momenta

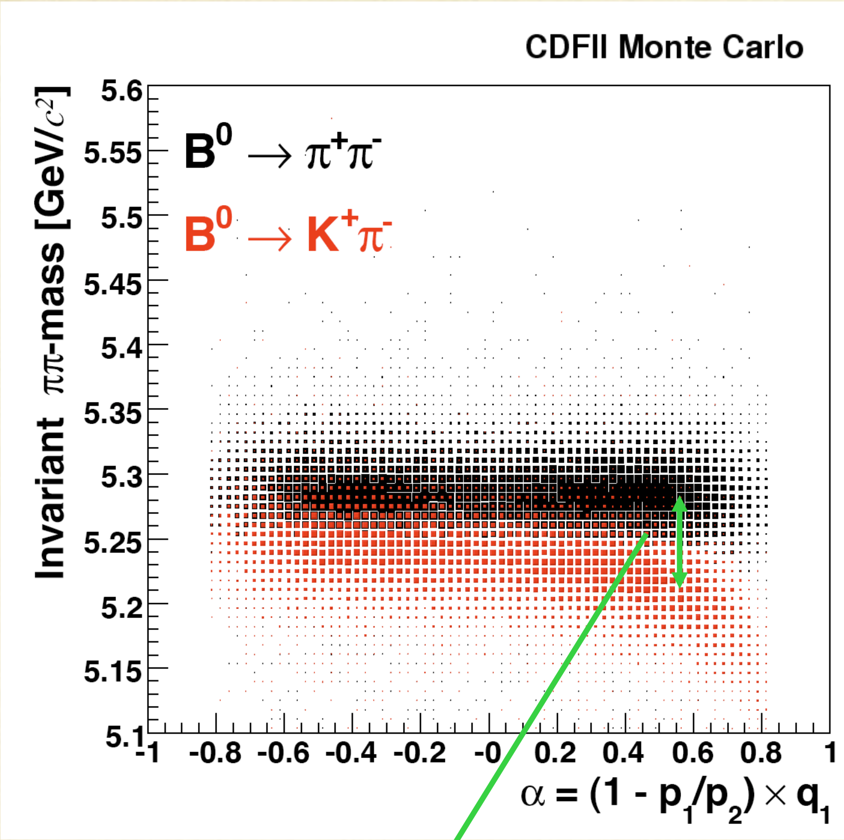
This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

Kinematics at work: $B^0 \rightarrow K^+\pi^-$ vs $B^0 \rightarrow \pi^+\pi^-$



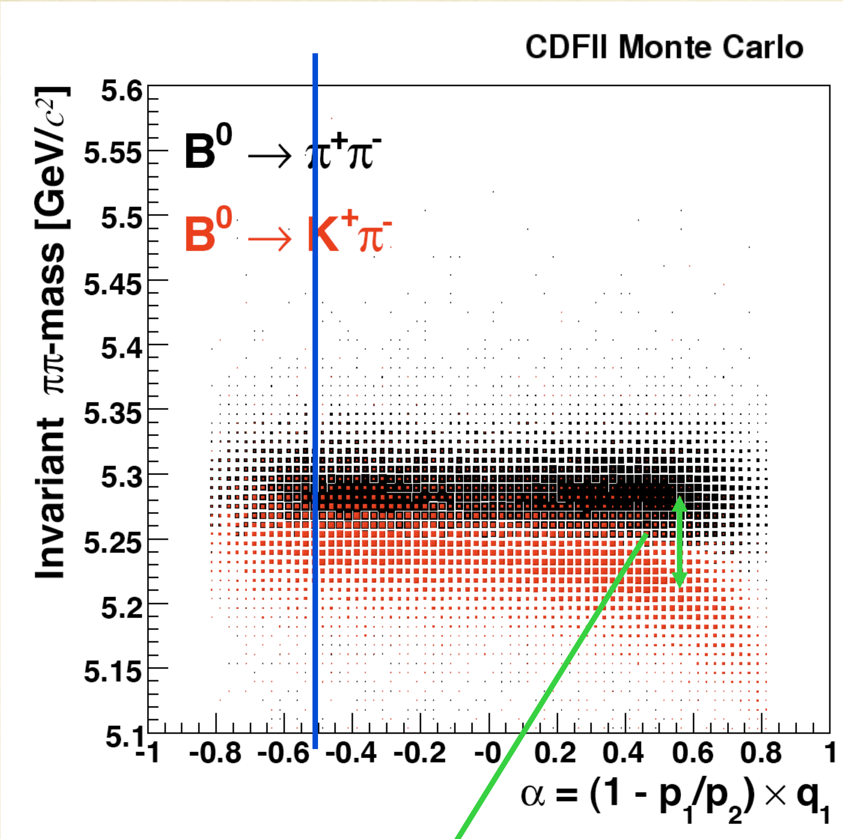
analytical function of momenta
$f(\alpha, p_{tot})$

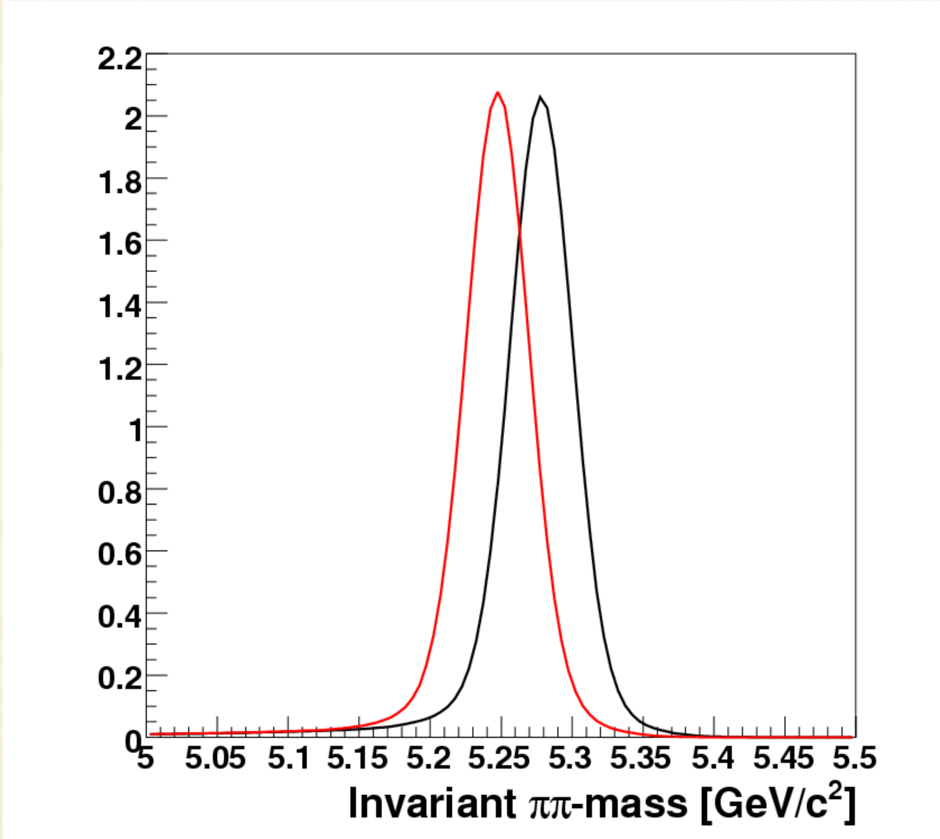
Kinematics at work: $B^0 \rightarrow K^+\pi^-$ vs $B^0 \rightarrow \pi^+\pi^-$



analytical function of momenta
$f(\alpha, p_{tot})$

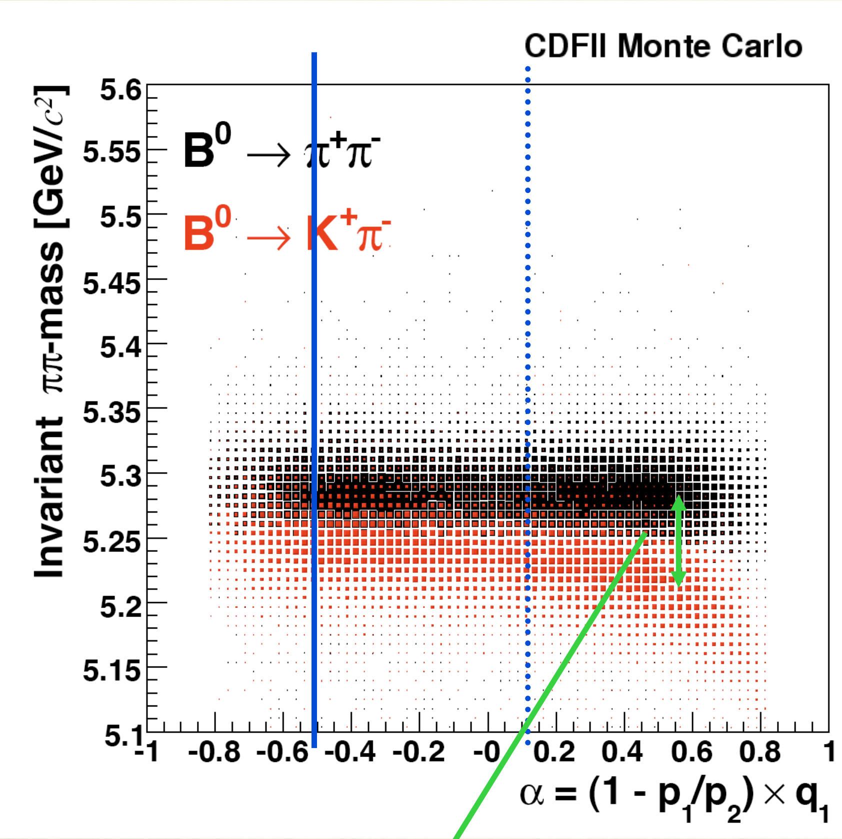
Kinematics at work: $B^0 \to K^+\pi^-$ vs $B^0 \to \pi^+\pi^-$

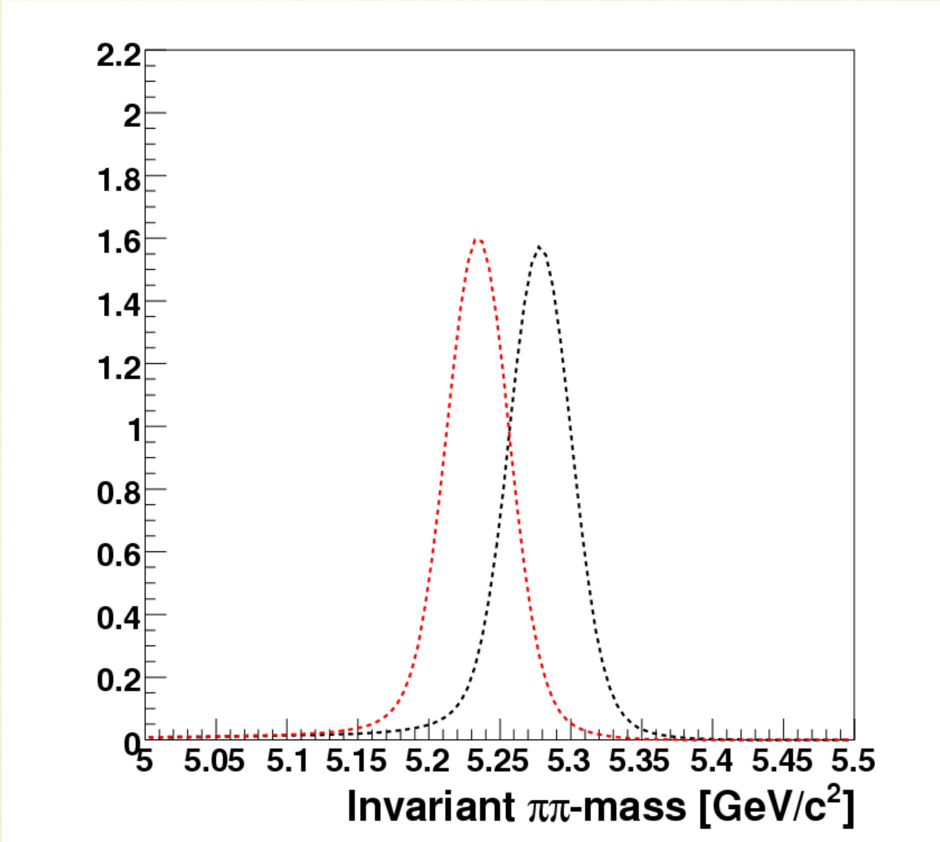




analytical function of momenta
$f(\alpha, p_{tot})$

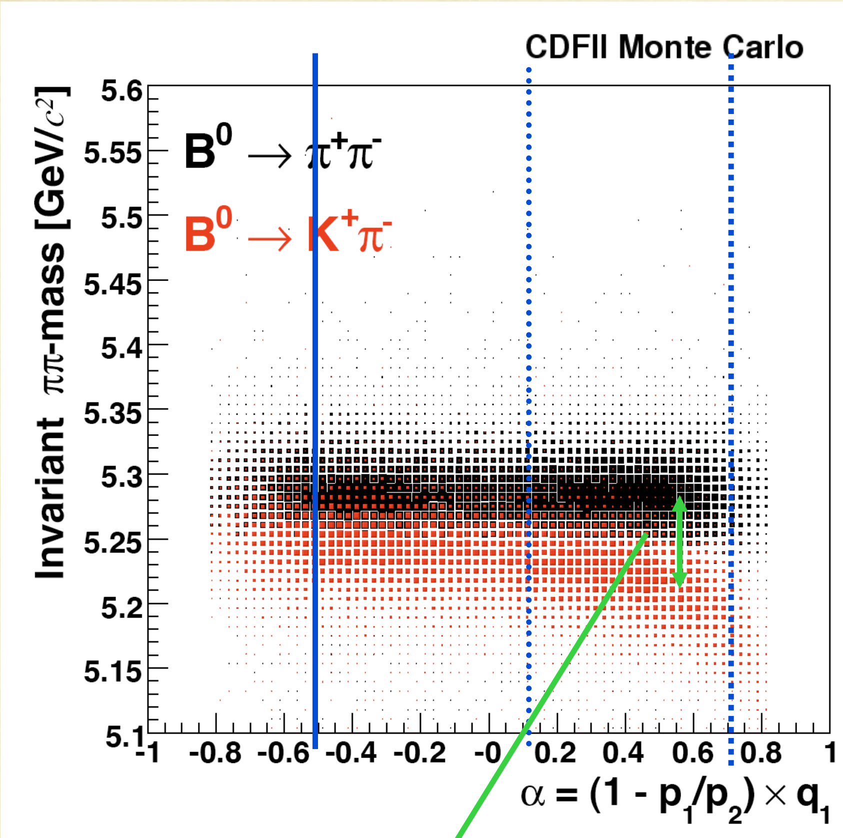
Kinematics at work: $B^0 \to K^+\pi^-$ vs $B^0 \to \pi^+\pi^-$

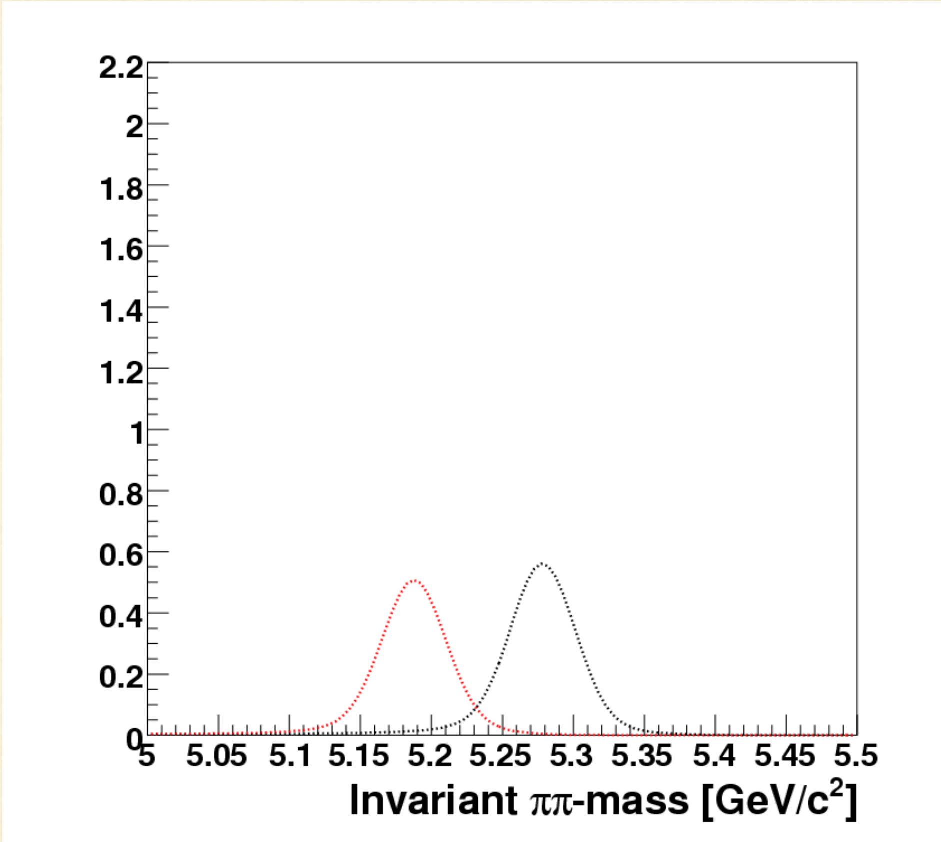




analytical function of momenta
$f(\alpha, p_{tot})$

Kinematics at work: $B^0 \to K^+\pi^-$ vs $B^0 \to \pi^+\pi^-$





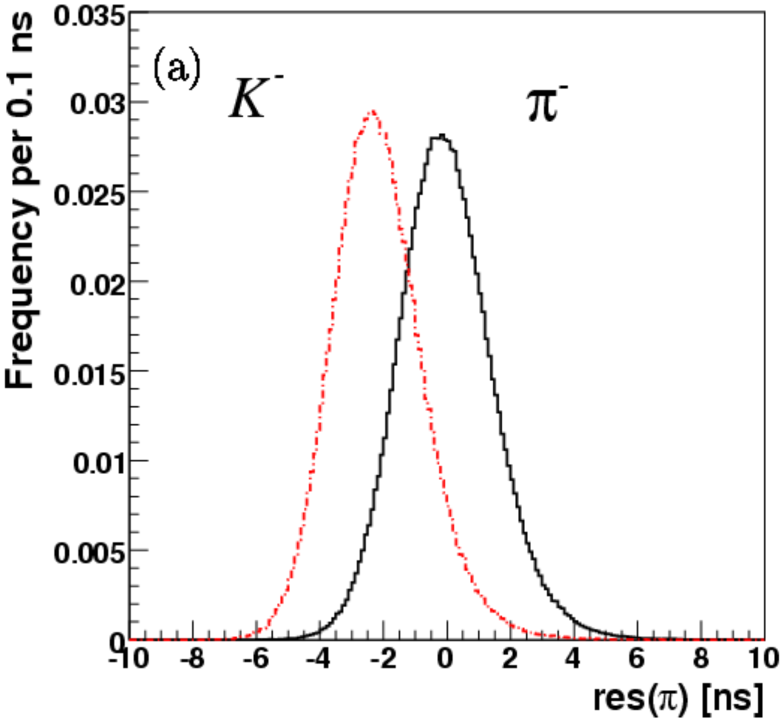
analytical function of momenta
$f(\alpha, p_{tot})$

Separation handle 3: PID

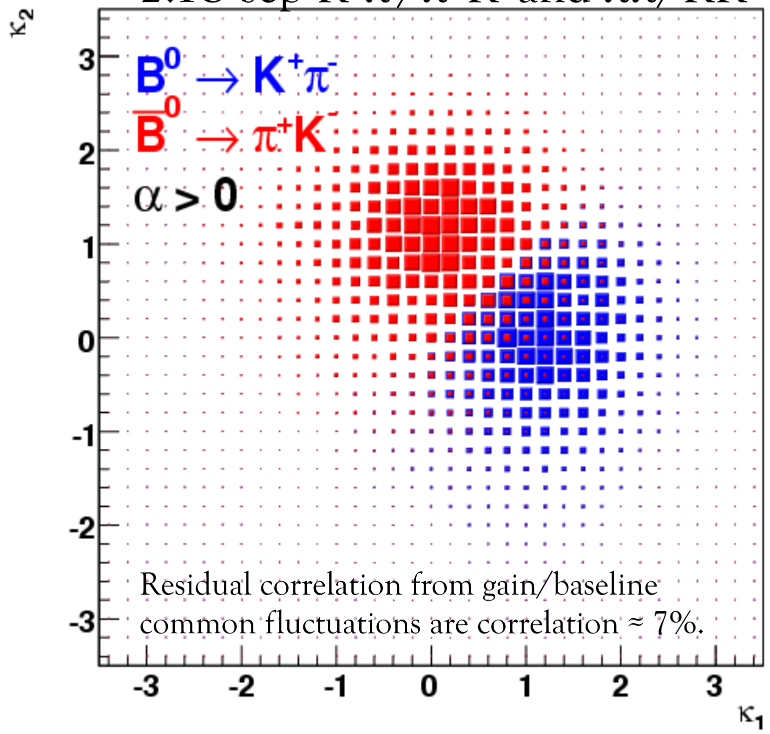
PID calibrated and parameterized from DATA. $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\,\pi^+$ and $\Lambda^0 \to p\pi^-$.

Detailed model includes tails, momentum dependence, two-track correlations.

1.5σ K/π separation at p>2GeV/c



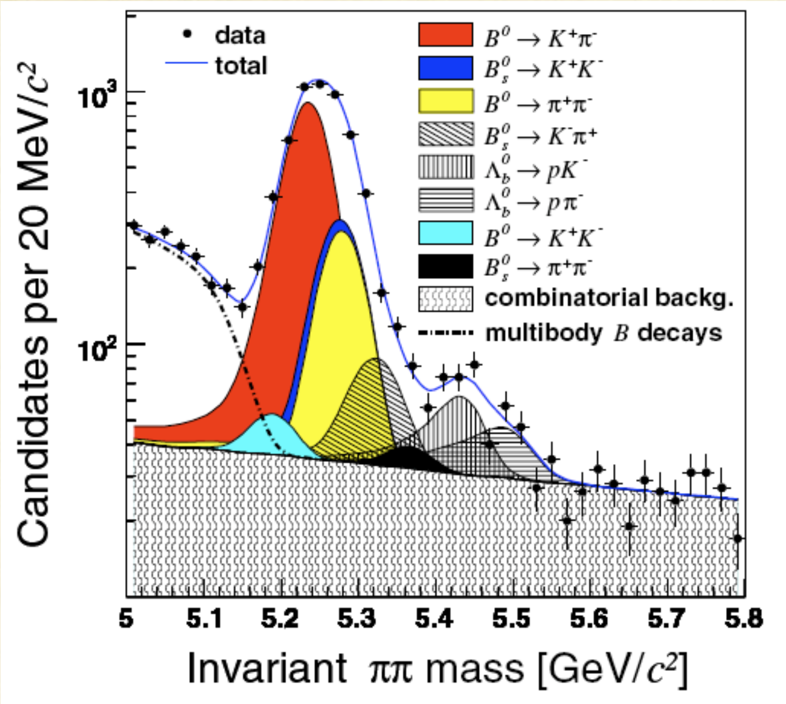
2.1σ sep $K^+\pi^-/\pi^+K^-$ and ππ/KK



Combined PID+kinematics fit is necessary. A cut on dE/dx does not help enough.

First and unique in CDF.

Results: search of rare modes



First observation of three new charmless decays modes: $B^0_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$, $\Lambda^0_b \to pK^-$. Published in Phys.Rev.Lett. 103, 031801(2009).

TABLE I. Yields and significances of rare mode signals. The first quoted uncertainty is statistical, the second is systematic.

Mode	N_s	Significance
$B_s^0 \to K^-\pi^+$	$230 \pm 34 \pm 16$	8.2σ
$B_s^0 \to \pi^+\pi^-$	$26 \pm 16 \pm 14$	$<3\sigma$
$B^0 \to K^+K^-$	$61 \pm 25 \pm 35$	$<3\sigma$
$\Lambda_b^0 \to pK^-$	$156 \pm 20 \pm 11$	11.5σ
$\Lambda_b^0 \to p\pi^-$	$110 \pm 18 \pm 16$	6.0σ

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
$B_s^0 \to K^-\pi^+$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.071 \pm 0.010 \pm 0.007$	$5.0 \pm 0.7 \pm 0.8$
$B_s^0 \to \pi^+\pi^-$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0\to \pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.007 \pm 0.004 \pm 0.005$	$0.49 \pm 0.28 \pm 0.36$ (<1.2 at 90% C.L.)
$B^0 \to K^+K^-$	$\frac{\mathcal{B}(B^0\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.020 \pm 0.008 \pm 0.006$	$0.39 \pm 0.16 \pm 0.12$ (<0.7 at 90% C.L.)
$\Lambda_b^0 \to pK^-$	$\frac{f_\Lambda}{f_d}\frac{\mathcal{B}(\Lambda_b^0\to pK^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.066 \pm 0.009 \pm 0.008$	$5.6 \pm 0.8 \pm 1.5$
$\Lambda_b^0 \to p\pi^-$	$\frac{f_\Lambda}{f_d}\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.042 \pm 0.007 \pm 0.006$	$3.5 \pm 0.6 \pm 0.9$

Results: Direct CPV (and more)

(To be published very soon on PRL)

Mode	$N_{b\to f}$	$N_{\bar{b}\to\bar{f}}$	CP–asymmetry
$B^0 \to K^+\pi^-$	1836 ± 61	2209 ± 64	$\frac{\mathcal{B}(\overline{B}^0\to K^-\pi^+)-\mathcal{B}(B^0\to K^+\pi^-)}{\mathcal{B}(\overline{B}^0\to K^-\pi^+)+\mathcal{B}(B^0\to K^+\pi^-)} = -0.086 \pm 0.023 \pm 0.009$ (3.5σ)
$B^0_s \to K^-\pi^+$	160 ± 26	70 ± 22	$\frac{\mathcal{B}(\overline{B}^0_s\to K^+\pi^-)-\mathcal{B}(B^0_s\to K^-\pi^+)}{\mathcal{B}(\overline{B}^0_s\to K^+\pi^-)+\mathcal{B}(B^0_s\to K^-\pi^+)} = +0.39 \pm 0.15 \pm 0.08$
$\Lambda^0_b \to pK^-$	80 ± 14	36 ± 11	$\frac{\mathcal{B}(\Lambda^0_b\to pK^-)-\mathcal{B}(\overline{\Lambda}^0_b\to \overline{p}K^+)}{\mathcal{B}(\Lambda^0_b\to pK^-)+\mathcal{B}(\overline{\Lambda}^0_b\to \overline{p}K^+)} = +0.37 \pm 0.17 \pm 0.03$
$\Lambda^0_b \to p\pi^-$	40 ± 10	38 ± 9	$\frac{\mathcal{B}(\Lambda^0_b\to p\pi^-)-\mathcal{B}(\overline{\Lambda}^0_b\to \overline{p}\pi^+)}{\mathcal{B}(\Lambda^0_b\to p\pi^-)+\mathcal{B}(\overline{\Lambda}^0_b\to \overline{p}\pi^+)} = +0.03 \pm 0.17 \pm 0.05$

First time

Result on B^0 mesons in agreement (same precision) with B-Factories using just $1fb^{-1}$, today on tape more than 5 fb^{-1}. Results on B^0_s and Λ^0_b are unique.

Mode	N	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
$B^0 \to \pi^+\pi^-$	1121 ± 63	$\frac{\mathcal{B}(B^0\to\pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.259 \pm 0.017 \pm 0.016$	$5.02 \pm 0.33 \pm 0.35$
$B^0_s \to K^+K^-$	1307 ± 64	$\frac{f_s}{f_d}\frac{\mathcal{B}(B^0_s\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.347 \pm 0.020 \pm 0.021$	$24.4 \pm 1.4 \pm 3.5$

High precision BR for large modes.

~1300 $B^0_s \to K^+K^-$ per fb^{-1} are the world's largest sample.

A first look at the DCPV in $B^0_s \to K^-\pi^+$

(2.5σ)

$$A_{CP}(B_s^0 \to K^-\pi^+) = \frac{BR(\overline{B}_s^0 \to K^+\pi^-) - BR(B_s^0 \to K^-\pi^+)}{BR(\overline{B}_s^0 \to K^+\pi^-) + BR(B_s^0 \to K^-\pi^+)} = 0.39 \pm 0.15(stat.) \pm 0.08(syst.)$$

Using PDG08 inputs for f_s and f_d:

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B_s^0 \to K^+\pi^-) - \Gamma(\overline{B}_s^0 \to K^-\pi^+)} = +0.83 \pm 0.41(stat.) \pm 0.12(syst.) \quad (\mathrm{SM} = +1)$$

First measurement of DCPV in the B^0_s
Sign and magnitude agree with SM predictions within uncertainties.

May shed light on the Belle and BaBar discrepancy. Assuming perfect SU(3) symmetry and neglecting annihilation diagrams *[Nucl. Phys. B697, 133,2004]* : $A_{CP}(B^0 \to \pi^+\pi^-) = A_{CP}(B^0_s \to K^-\pi^+)$.
Note that our central value for A_{CP} is just in the middle of B-Factories results.

Detector-induced charge asymmetry

$\boxed{-0.086 \pm 0.023 \pm 0.009 \text{ in } 1\text{fb}^{-1}}$

$$\mathcal{A}_{\mathrm{CP}}(B^0 \to K^+\pi^-) = \frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)} = \frac{\hat{f}_{\overline{B}^0 \to K^-\pi^+} \cdot \frac{\varepsilon(B^0 \to K^+\pi^-)}{\varepsilon(\overline{B}^0 \to K^-\pi^+)} - \hat{f}_{B^0 \to K^+\pi^-}}{\hat{f}_{\overline{B}^0 \to K^-\pi^+} \cdot \frac{\varepsilon(B^0 \to K^+\pi^-)}{\varepsilon(\overline{B}^0 \to K^-\pi^+)} + \hat{f}_{B^0 \to K^+\pi^-}}$$

To extract reliable and precise CP asymmetry measurement need to measure detector-induced charge asymmetry.

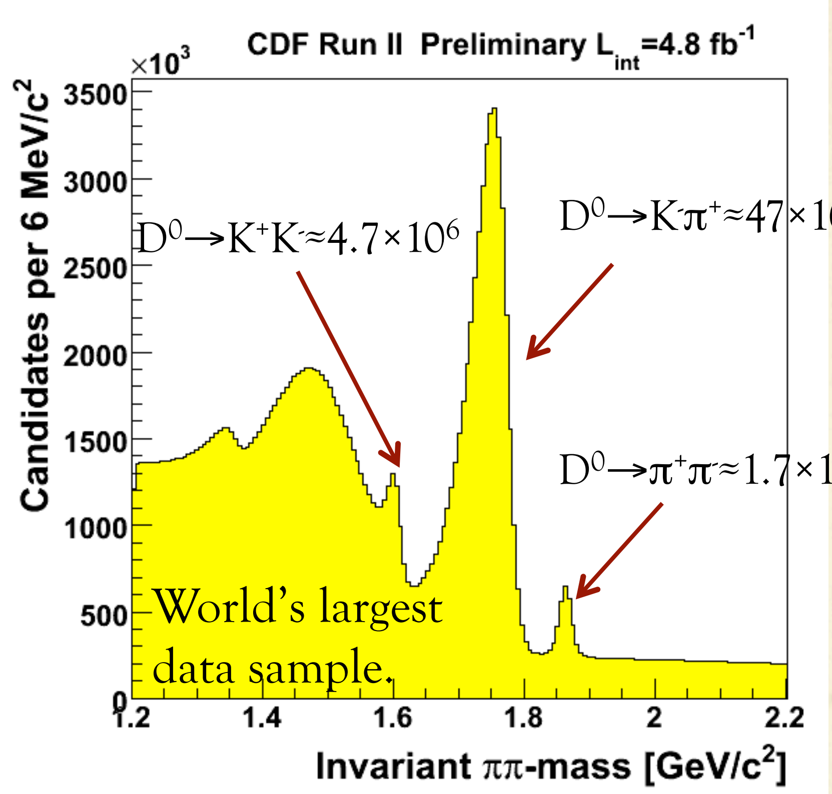
Although simulation is accurate, it is hard to reach precision less than % level.
Use the huge untagged $D^0 \to K^-\pi^+$ data sample, collected with the hadronic trigger:

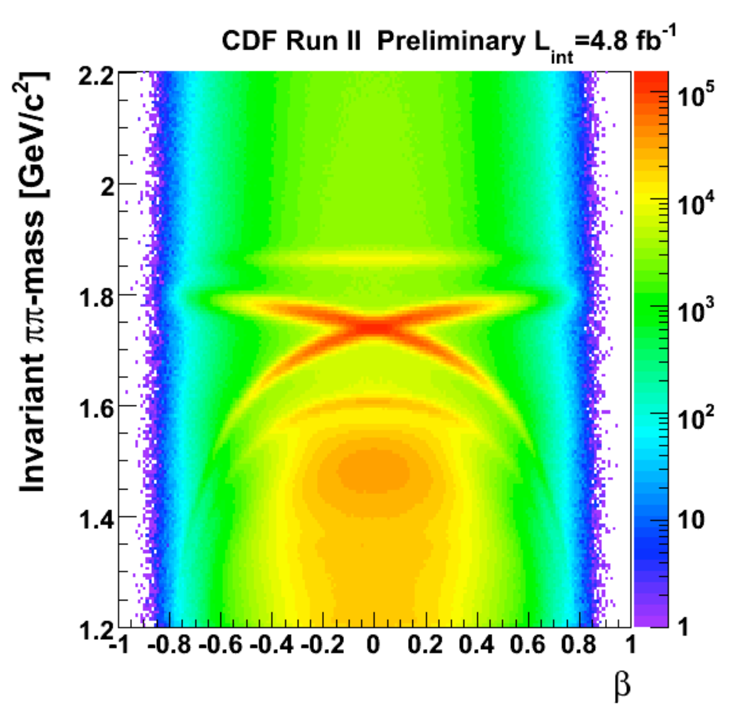
$$\frac{\mathcal{B}(\overline{D}^0 \to K^+\pi^-) - \mathcal{B}(D^0 \to K^-\pi^+)}{\mathcal{B}(\overline{D}^0 \to K^+\pi^-) + \mathcal{B}(D^0 \to K^-\pi^+)} = \frac{\hat{f}_{\overline{D}^0 \to K^+\pi^-} \cdot \frac{\varepsilon(D^0 \to K^-\pi^+)}{\varepsilon(\overline{D}^0 \to K^+\pi^-)} - \hat{f}_{D^0 \to K^-\pi^+}}{\hat{f}_{\overline{D}^0 \to K^+\pi^-} \cdot \frac{\varepsilon(D^0 \to K^-\pi^+)}{\varepsilon(\overline{D}^0 \to K^+\pi^-)} + \hat{f}_{D^0 \to K^-\pi^+}} \ll 10^{-3}$$

Count the number of D^0 and antiD^0 to extract efficiency ratio $\varepsilon(K^-\pi^+)/\varepsilon(K^+\pi^-)$.
CP-invariant production → same number of particle/antiparticle at production.
Data-driven technique and uncertainty depends just on statistics size.

Disentangling $D^0 \to K^- \pi^+$ and $\overline{D}^0 \to K^+ \pi^-$

"Untagged sample"





Charged momentum asymmetry: $\beta = \dfrac{p^+ - p^-}{p^+ + p^-}$

Use full $B \to h^+h^-$ technology [*PRL97,211802(2006); PRL103,031801(2009); and PhD. Thesis FERMILAB-THESIS-2007-57*]. A "quasi" perfect separation using just the 2-dim view ($\beta, m_{\pi\pi}$).

Small data sample ~150pb^{-1} used already in the $B \to hh$ analysis to extract precise correction for the measurement of CP asymmetry in $B^0 \to K^+ \pi^-$.

A new scenario: Charm Mixing

Huge data samples and know-how acquired with $B \to h^+h^-$ analysis put CDF in a dominant position in charm physics.

$$x_D = \frac{\Delta m_D}{\Gamma_D} \qquad y_D = \frac{\Delta\Gamma_D}{2\Gamma_D}$$

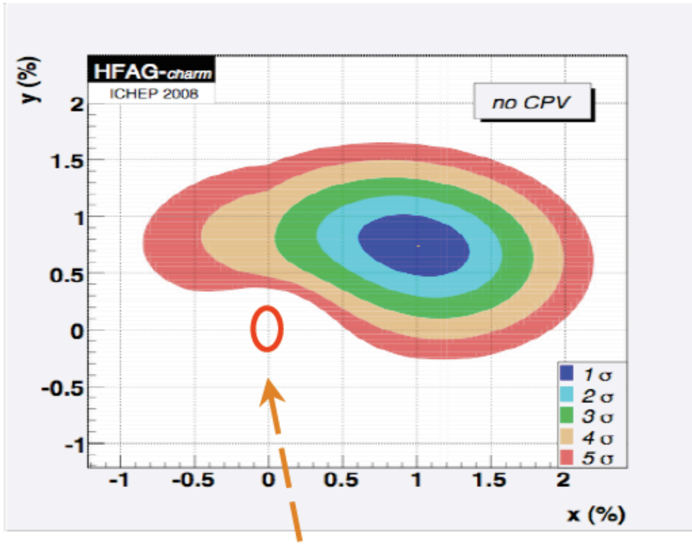
$$\boxed{\begin{array}{l} x_D = (1.00 \pm 0.26)\ \% \\ y_D = (0.76 \pm 0.18)\ \% \end{array}}$$

“Evidence” of D^0 mixing open new scenarios:

$$A_{CP}(t) = (x_D \sin\phi_{CP} - y_D \varepsilon_{CP} \cos\phi_{CP})(t/\tau) + \ldots$$

$x_D, y_D = 0.01$, $\sin\phi^{SM}_{CP}$, $\varepsilon^{SM}_{CP} < 0.001$

➡ $A^{SM}_{CP}(t) < 10^{-5}$ vs. $A^{NP}_{CP}(t) < 10^{-2}$



$$\boxed{(x_D, y_D) = (0,0)}$$

A nice window to look inside.
Are D^0-mixing, $\sin(2\beta s)$, $A_{FB}(b \to K\mu\mu)$, $A_{CP}(B^0 \to K\pi)$ indicating the presence of 4th generation?

Charm totally complementary to direct searches in LHC age, not yet deeply explored.

Measurement of Time-integrated CP-asymmetries in $D^0 \rightarrow h^+h^-$ (in progress)

$A_{CP}(D^0 \to h^+h^-)$: current status

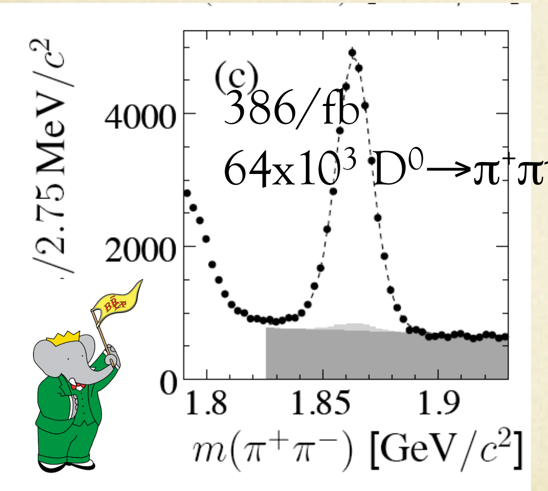
D^0 oscillations can generate time dependent CP asymmetries that survive integrating over time. Crucial to investigate with extreme precision (per mil level and beyond):

Flavor tag from $D^{*+} \to D^0\pi^+$

$$A_{CP}^{\pi\pi} = \frac{\Gamma(D^0 \to \pi^-\pi^+) - \Gamma(\overline{D}^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^-\pi^+) + \Gamma(\overline{D}^0 \to \pi^+\pi^-)}$$

(the same for K^+K^-)

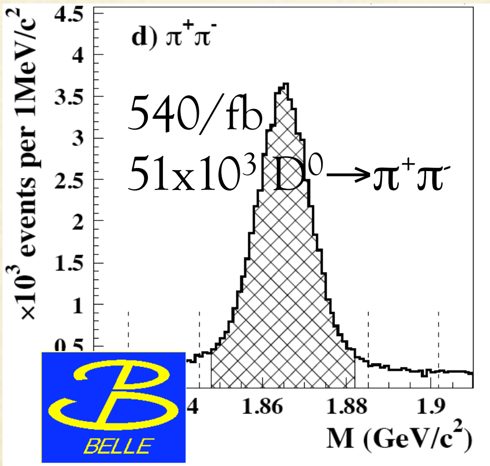
PRL100,061803(2008)



$A_{CP}^{KK} = [+0.00 \pm 0.34 \pm 0.13]\%$

$A_{CP}^{\pi\pi} = [-0.24 \pm 0.52 \pm 0.22]\%$

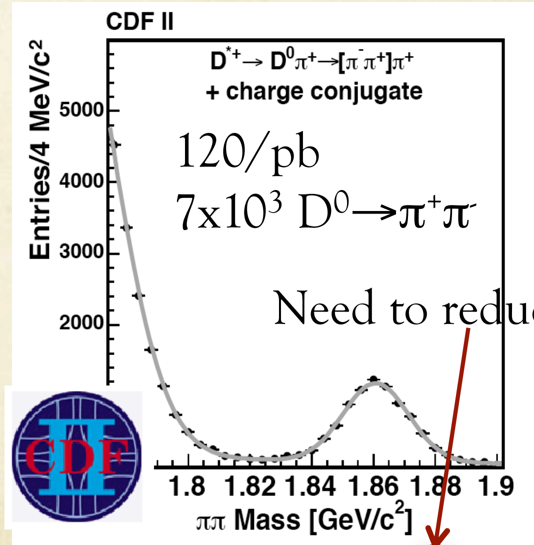
PLB670,190-195(2008)



$A_{CP}^{KK} = [+0.43 \pm 0.30 \pm 0.11]\%$

$A_{CP}^{\pi\pi} = [+0.43 \pm 0.52 \pm 0.12]\%$

PRL94,122001(2005)

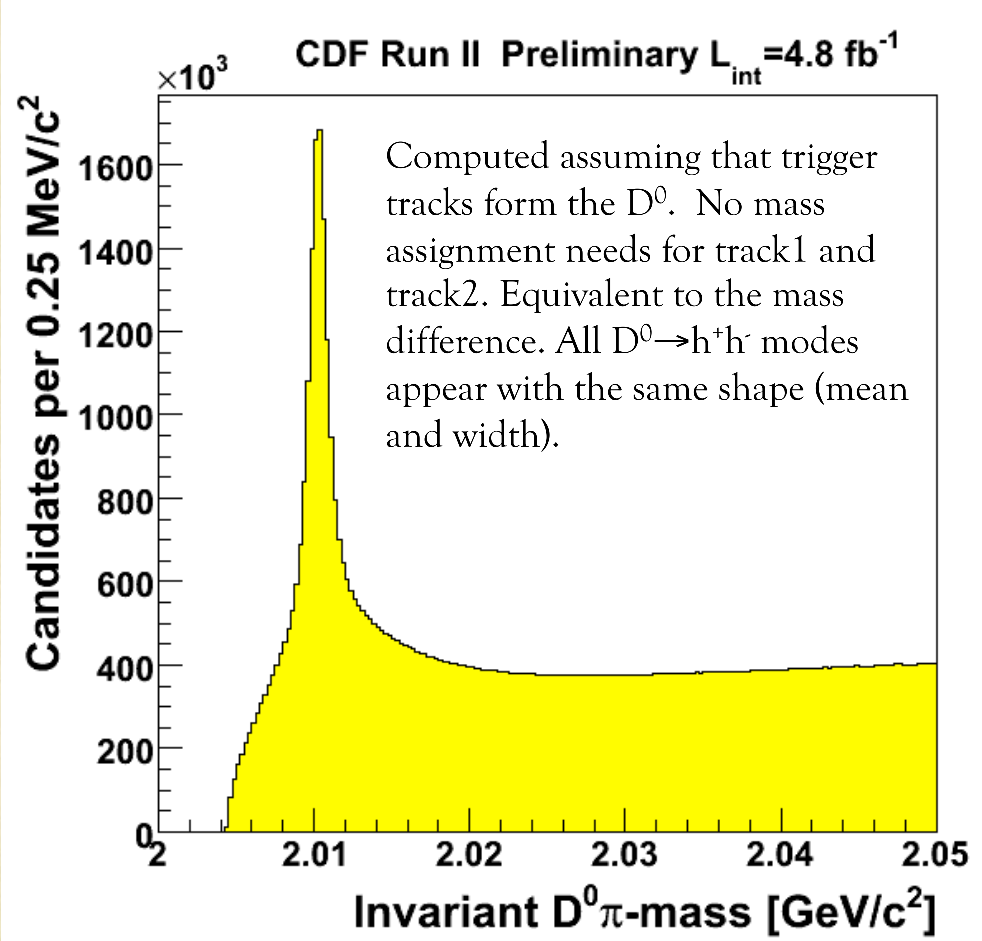


Need to reduce syst.

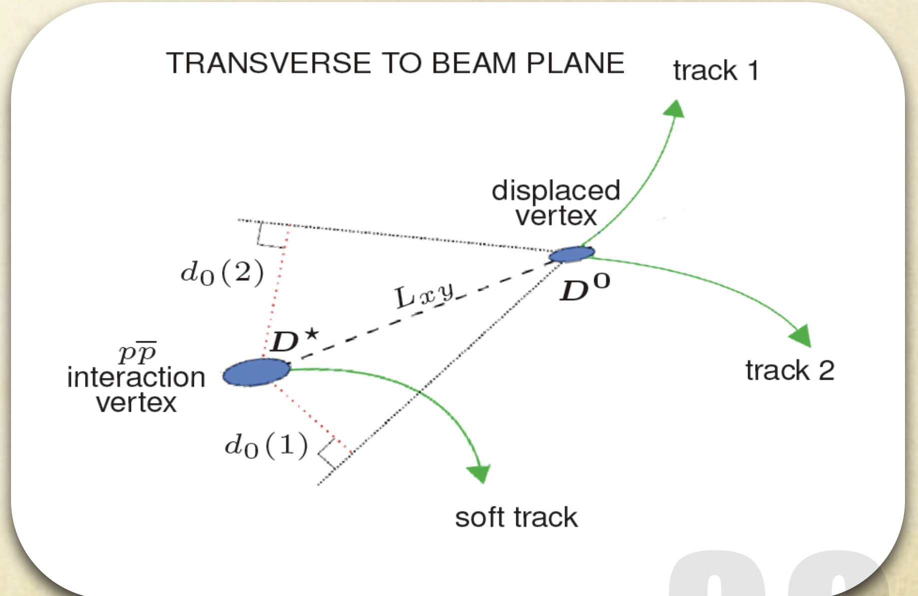
$A_{CP}^{KK} = [+2.0 \pm 1.2 \pm 0.6]\%$

$A_{CP}^{\pi\pi} = [+1.0 \pm 1.3 \pm 0.6]\%$

Tagged $D^0 \to h^+h^-$ from $D^{*+} \to D^0\pi^+$



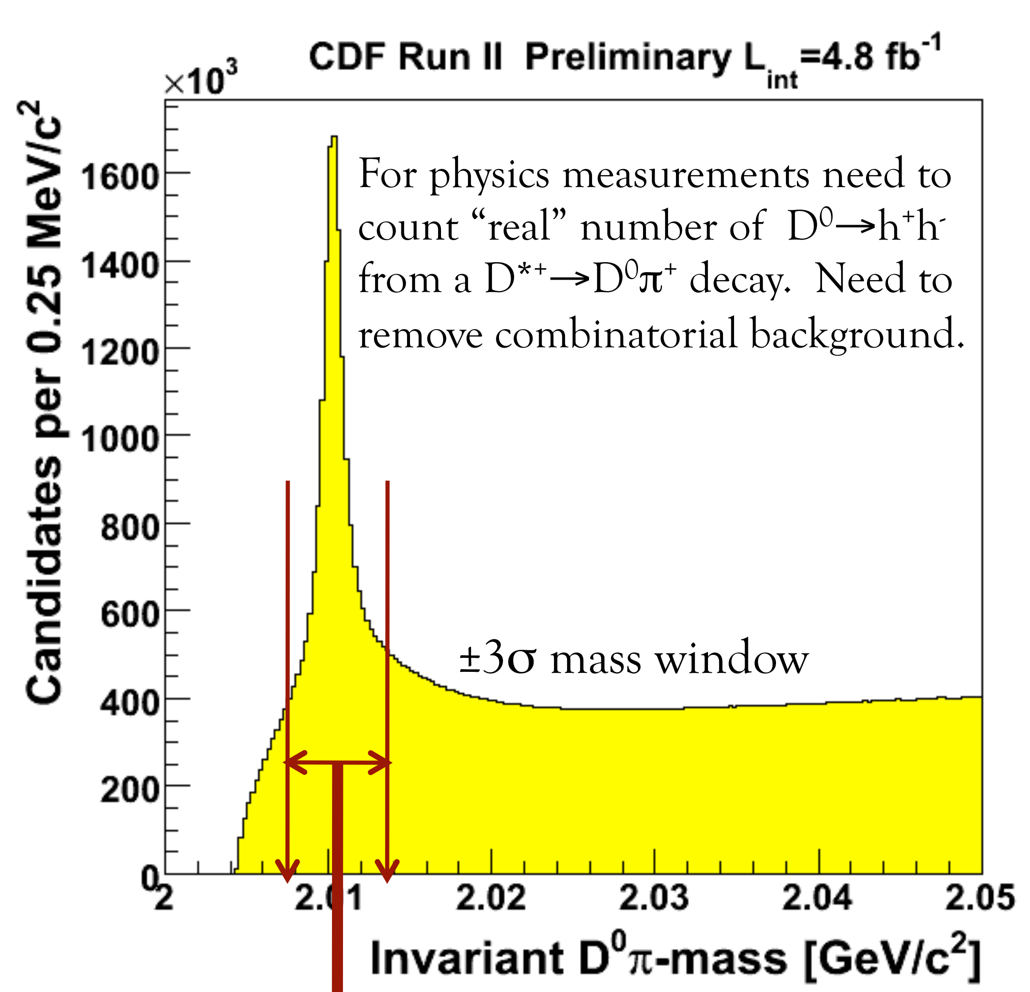
Soft pion associated to the D^0 trigger candidate.
Loop on all tracks in the event (except tracks from candidate).
Transverse momentum $p_T(\pi_s)$>0.4 GeV/c
Invariant $D^0\pi$ mass <2.05 GeV

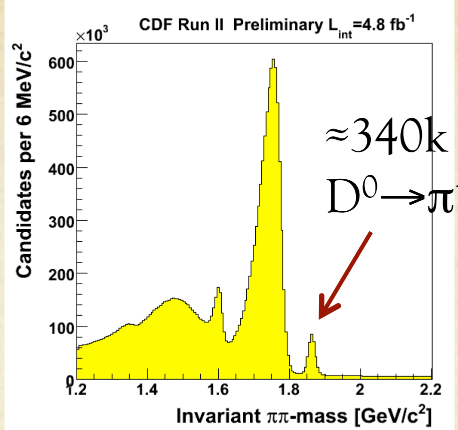


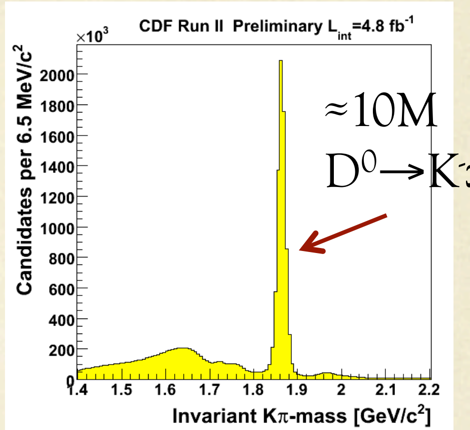
$$p^\mu(D^0) \equiv \left(\sqrt{(\vec{p}_1 + \vec{p}_2)^2 + M^2_{D^0}}, \vec{p}_1 + \vec{p}_2\right)$$

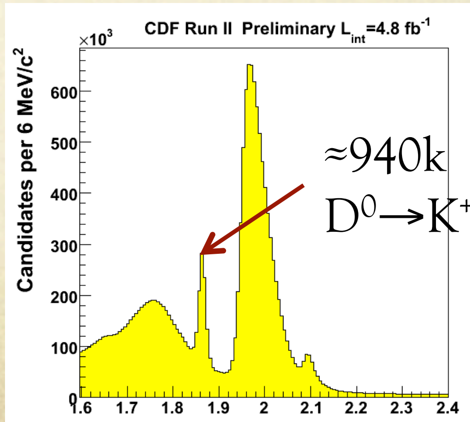
D^* vertex does not help, D^0 collinear to π_s.

Tagged $D^0 \to h^+h^-$ from $D^{*+} \to D^0\pi^+$







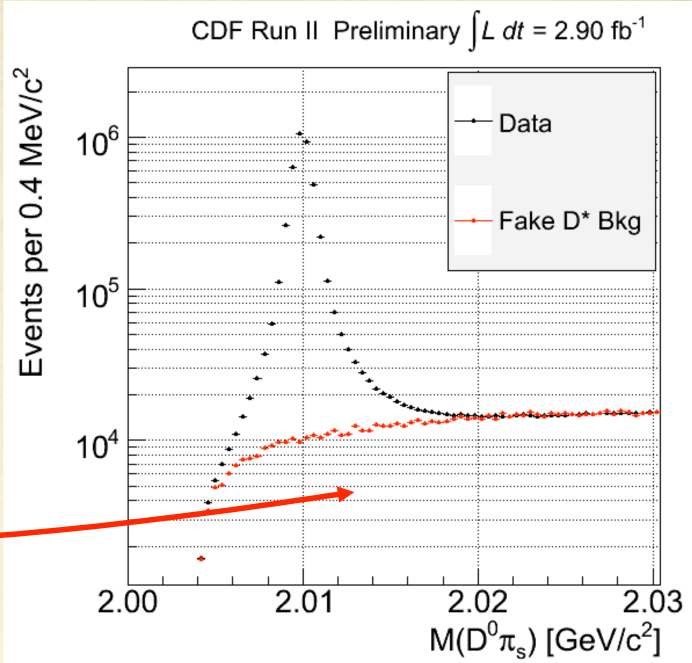


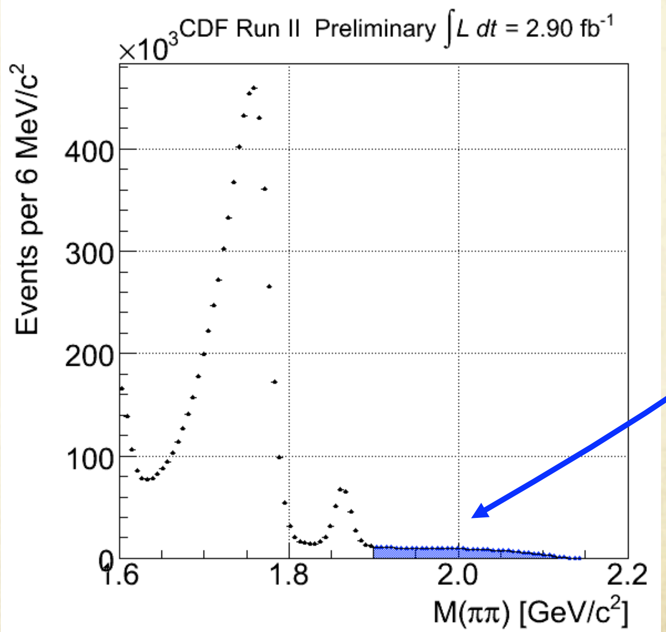
Counting of $D^{*+} \to D^0\pi^+$ decays

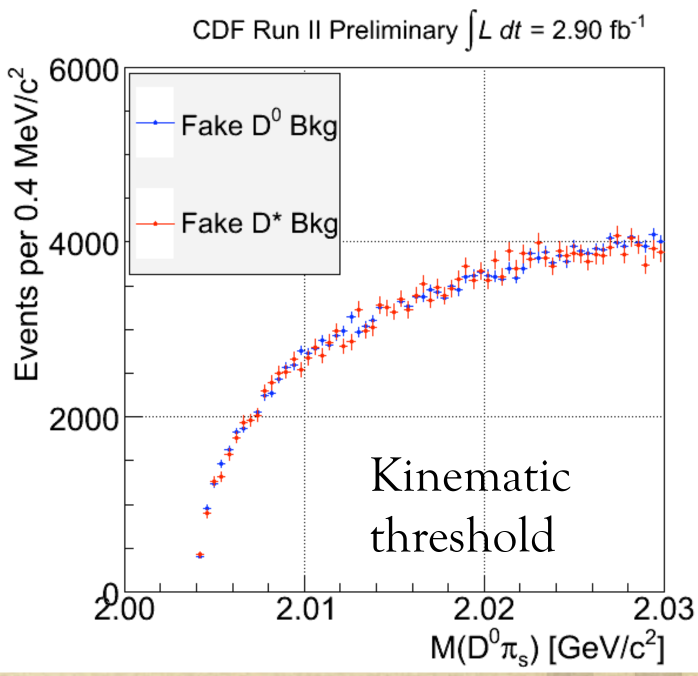
Need to remove background in D*-invariant mass:

Fake D* = real D^0 + random soft pion
Model: combining a D^0 candidate with a soft pion of another D* candidate.

Fake D^0 and Fake D*= three random tracks
Model: higher mass sideband in ππ-invariant mass.

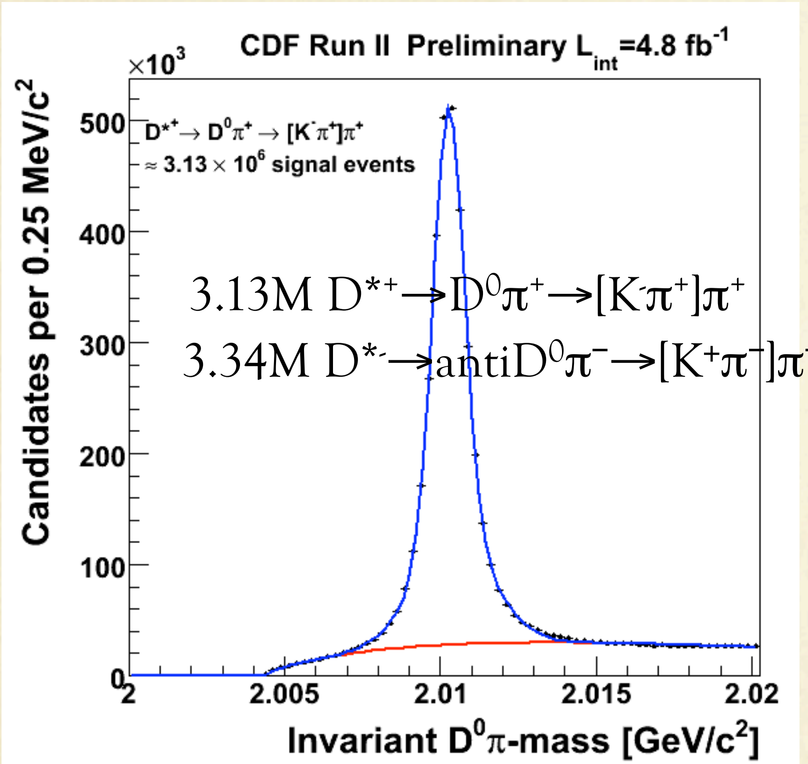






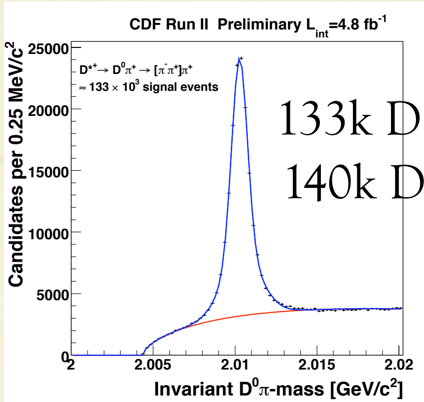
$D^{*+} \rightarrow D^0\pi^+ \rightarrow [h^-h^+]\,\pi^+$

Select events with invariant D^0-mass in $\pm 3\sigma$ mass window around D^0 nominal mass value



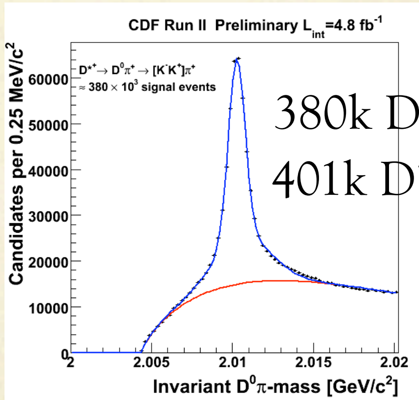
3.13M $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\pi^+$

3.34M $D^{*-} \rightarrow \text{anti}D^0\pi^- \rightarrow [K^+\pi^-]\pi^-$



133k $D^{*+} \rightarrow D^0\pi^+ \rightarrow [\pi^-\pi^+]\pi^+$

140k $D^{*-} \rightarrow \text{anti}D^0\pi^- \rightarrow [\pi^+\pi^-]\pi^-$



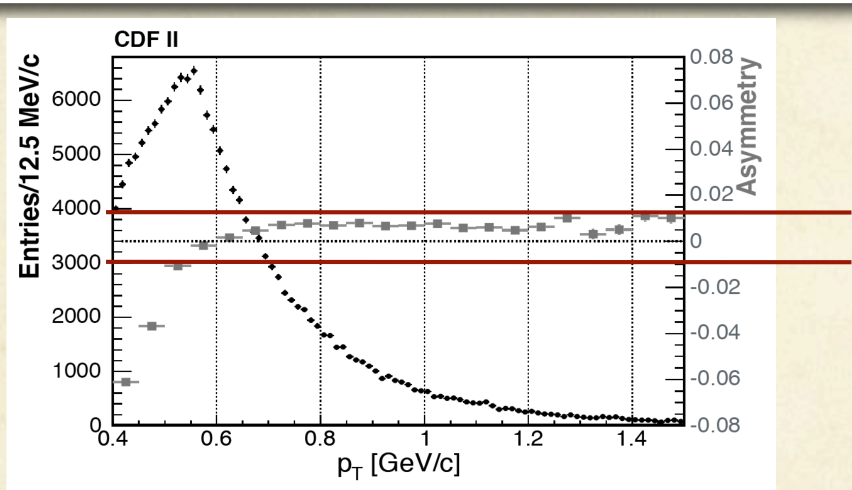
380k $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-K^+]\pi^+$

401k $D^{*-} \rightarrow \text{anti}D^0\pi^- \rightarrow [K^+K^-]\pi^-$

CDF now has the world's largest data samples and is taking data at a rate 10xBelle.

Analysis strategy

$$\frac{\Gamma(D^{*-} \to \overline{D}^0 \pi_s^- \to [h^+h^-]\pi_s^-)}{\Gamma(D^{*+} \to D^0 \pi_s^+ \to [h^+h^-]\pi_s^+)} = \frac{N_{h^+h^-\pi_s^-}}{N_{h^+h^-\pi_s^+}} \cdot \cancel{\frac{\varepsilon_{h^+h^-}}{\varepsilon_{h^+h^-}}} \cdot \boxed{\frac{\varepsilon_{\pi_s^+}}{\varepsilon_{\pi^-}}}$$



$\pm 1\%$

- D*-tag provide D^0 decay flavor at production.
- Need "extremely accurate" correction for efficiency ratio $\varepsilon(\pi_s^+)/e(\pi_s^-)$.
- Use D*-tagged and untagged $D^0 \to K^-\pi^+$ to evaluate $\varepsilon(\pi_s^+)/e(\pi_s^-)$.

Soft pion efficiency ratio $\varepsilon(\pi_s^+)/\varepsilon(\pi_s^-)$

Use a combined measurement of untagged and D*-tagged $D^0 \to K^-\pi^+$.

Tagged D^0 decays

$$\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^- \to [K^+\pi^-]\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+ \to [K^-\pi^+]\pi_s^+)} = \frac{N_{K^+\pi^-\pi_s^-}}{N_{K^-\pi^+\pi_s^+}} \cdot \boxed{\frac{\varepsilon_{K^-\pi^+}}{\varepsilon_{K^+\pi^-}}} \cdot \frac{\varepsilon_{\pi_s^+}}{\varepsilon_{\pi_s^-}}$$

$$\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^- \to [K^+\pi^-]\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+ \to [K^-\pi^+]\pi_s^+)} = \cancel{\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+)}} \cdot \frac{\Gamma(\overline{D}^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)}$$

strong interaction

Untagged D^0 decays

$$\frac{\Gamma(\overline{D}^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = \frac{N_{K^+\pi^-}}{N_{K^-\pi^+}} \cdot \boxed{\frac{\varepsilon_{K^-\pi^+}}{\varepsilon_{K^+\pi^-}}}$$

Allow CP violation in $D^0 \to K^-\pi^+$ decays

Soft pion efficiency ratio $\varepsilon(\pi_s^+)/\varepsilon(\pi_s^-)$

Use a combined measurement of untagged and D*-tagged $D^0 \to K^-\pi^+$.

Tagged D^0 decays

$$\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^- \to [K^+\pi^-]\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+ \to [K^-\pi^+]\pi_s^+)} = \boxed{\frac{N_{K^+\pi^-\pi_s^-}}{N_{K^-\pi^+\pi_s^+}} \cdot \frac{\varepsilon_{K^-\pi^+}}{\varepsilon_{K^+\pi^-}} \cdot \frac{\varepsilon_{\pi_s^+}}{\varepsilon_{\pi_s^-}}}$$

$$\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^- \to [K^+\pi^-]\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+ \to [K^-\pi^+]\pi_s^+)} = \cancel{\frac{\Gamma(D^{*-} \to \overline{D}^0\pi_s^-)}{\Gamma(D^{*+} \to D^0\pi_s^+)}} \cdot \frac{\Gamma(\overline{D}^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)}$$

strong interaction

Untagged D^0 decays

$$\frac{\Gamma(\overline{D}^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = \boxed{\frac{N_{K^+\pi^-}}{N_{K^-\pi^+}} \cdot \frac{\varepsilon_{K^-\pi^+}}{\varepsilon_{K^+\pi^-}}}$$

=

Allow CP violation in $D^0 \to K^-\pi^+$ decays

Soft pion efficiency ratio $\varepsilon(\pi_s^+)/\varepsilon(\pi_s^-)$ (II)

$$\frac{\varepsilon_{\pi_s^+}}{\varepsilon_{\pi_s^-}} = \frac{N_{K^+\pi^-}}{N_{K^-\pi^+}} \cdot \cancel{\frac{\varepsilon_{K^-\pi^+}}{\varepsilon_{K^+\pi^-}}} \cdot \frac{N_{K^-\pi^+\pi_s^+}}{N_{K^+\pi^-\pi_s^-}} \cdot \cancel{\frac{\varepsilon_{K^+\pi^-}}{\varepsilon_{K^-\pi^+}}}$$

From untagged $D^0 \rightarrow K^-\pi^+$ decays

From D*tagged $D^0 \rightarrow K^-\pi^+$ decays

Just count number of particle and anti-particle of untagged and tagged $D^0 \rightarrow K^-\pi^+$.
Totally data driven technique. No external MC inputs.

-All detector induced charge asymmetries accounted for.
-Direct CP-violating asymmetry in $D^0 \rightarrow K^-\pi^+$ does not affect measurement.
-CP-invariant production → same number of particle/antiparticle at production.
-Detector symmetric in pseudo-rapidity (η) → cancellation of beam-drag effects.

Work in progress, but expect cancellation works to the percent level, ⇒ expect systematics on A_{CP} well below 0.1%

Possible issues

- In principle non trivial work: reweight of distributions (p_T,η,ϕ) of untagged decays to tagged decays.
  - Differences are small, reweight could be negligible.
- Check efficiency factorization at this precision level.
- Generation of very high statistics MC samples.
  - Essential to test assumptions and cancellation.
  - Could be a challenge.

Prospects for $A_{CP}(D^0 \to h^+h^-)$ on 4.8 fb^{-1}

Assuming: $\sigma_N \cong \sigma_{\overline{N}} \cong 1/\sqrt{N} \Rightarrow \sigma_{A_{CP}} = 1/\sqrt{N+\overline{N}}$

$\left\{ \begin{array}{l} 273\text{k } D^0 \to \pi^+\pi^- \\ 781\text{k } D^0 \to K^+K^- \end{array} \right.$

Measurement (%)	CDF (4.8/fb)	Current BaBar/Belle
$A_{CP}(D^0 \to \pi^+\pi^-)$	xxx ± 0.19(stat) ± xxx (syst)	0.52(stat)
$A_{CP}(D^0 \to K^+K^-)$	xxx ± 0.11(stat) ± xxx (syst)	0.3(stat)

- A good step forward in precision, maybe x2 in statistics by end of 2011.
- For CPV in mixing, can combine $\pi^+\pi^-$ and K^+K^- . Precision below 0.1%
- Potential to actually see an effect of few per mil !
- Long lever arm in lifetime helps.

Conclusions

- Performed the measurement of $B \to h^+h^-$ decays in 1/fb.
  - First observation of $B^0_s \to K^+K^-$ [PRL 97, 211802 (2006)]
  - First observation of $B^0_s \to K^-\pi^+$, $\Lambda^0_b \to pK^-$, $\Lambda^0_b \to p\pi^-$ [PRL 103, 031801 (2009)]
  - Measurement of all direct CPV and precision BR [PRL in progress].
  - Developed several new and innovative analysis techniques.
- Co-convener of the BMLCPV CDF-Group
  - $\sin(2\beta_s)$ in $B^0_s \to J/\psi\phi$, lifetime of b-hadrons, D^0-mixing, γ from $B \to DK$ decays, BR/CPV in $B \to h^+h^-$, etc.
- Member of Silicon Vertex Trigger group in CDF.
  - Software and hardware maintenance (pager carrier).

Future

- Huge amount of data and an enormous know-how to exploit.
  - CDF is taking data, 10 fb^{-1} by the end of 2011.
- $B \to h^+h^-$ analysis:
  - Update to full statistics A_{CP}/BR $B \to h^+h^-$ analysis.
  - Adding lifetime component and flavour tagging for the time-dependent measurement $A_{CP}(t)$ in $B^0_s \to K^+K^-$ and $B^0 \to \pi^+\pi^-$.
- Fully exploit CDF potentialities in Charm Physics:
  - Finalize asap time-integrated A_{CP} in CS $D^0 \to h^+h^-$ decays.
  - Measurement of D^0-mixing parameters:
    - Cabibbo Favored $D^0 \to K^-\pi^+$ decays.
    - Lifetime ratio $\tau(D^0 \to h^-h^+)/\tau(D^0 \to K^-\pi^+)$.

Backup

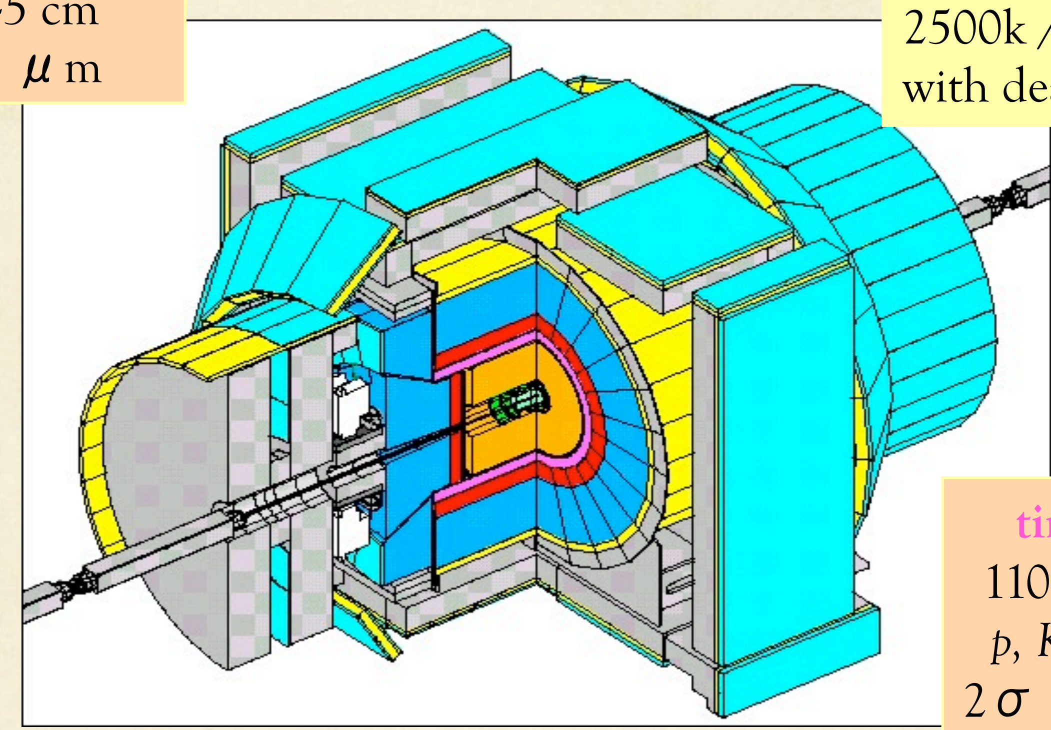
The CDF II detector

7 to 8 silicon layers
$1.6 < r < 28$ cm, $|z|<45$ cm
$|\eta| \leq 2.0$ σ(hit) ~ 15 μm

1.4 T magnetic field
Lever arm 132 cm

132 ns front end
chamber tracks at L1
silicon tracks at L2
2500k / 300k / 100 Hz
with dead time < 5%

Some resolutions:
p_T~0.15% p_T (c/GeV)
J/Ψ mass ~14 MeV
EM E ~ 16%/√E
Had E ~ 80%/√E
d_0 ~40 μm
(includes beam spot)



time-of-flight
110 ps at 150 cm
p, K, π identific.
2σ at p_T<1.6 GeV

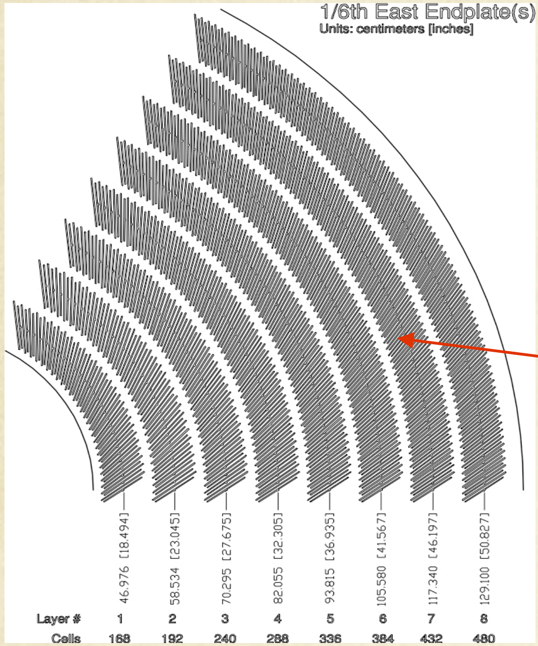
96 layer drift chamber
$|\eta| \leq 1.0$, $44 < r < 132$ cm, $|z|<155$ cm
30k channels, σ(hit) ~ 140 μm
dE/dx for p, K, π identification

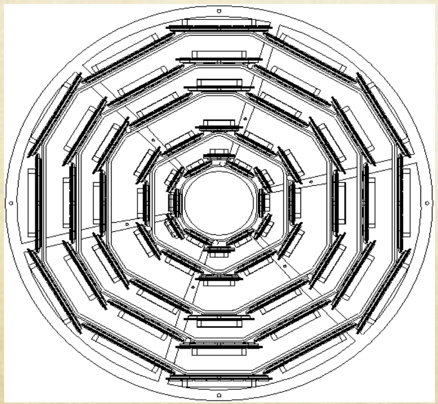
scintillator and tile/fiber sampling calorimetry
$|\eta| < 3.64$

μ coverage
$|\eta| \leq 1.5$
84% in

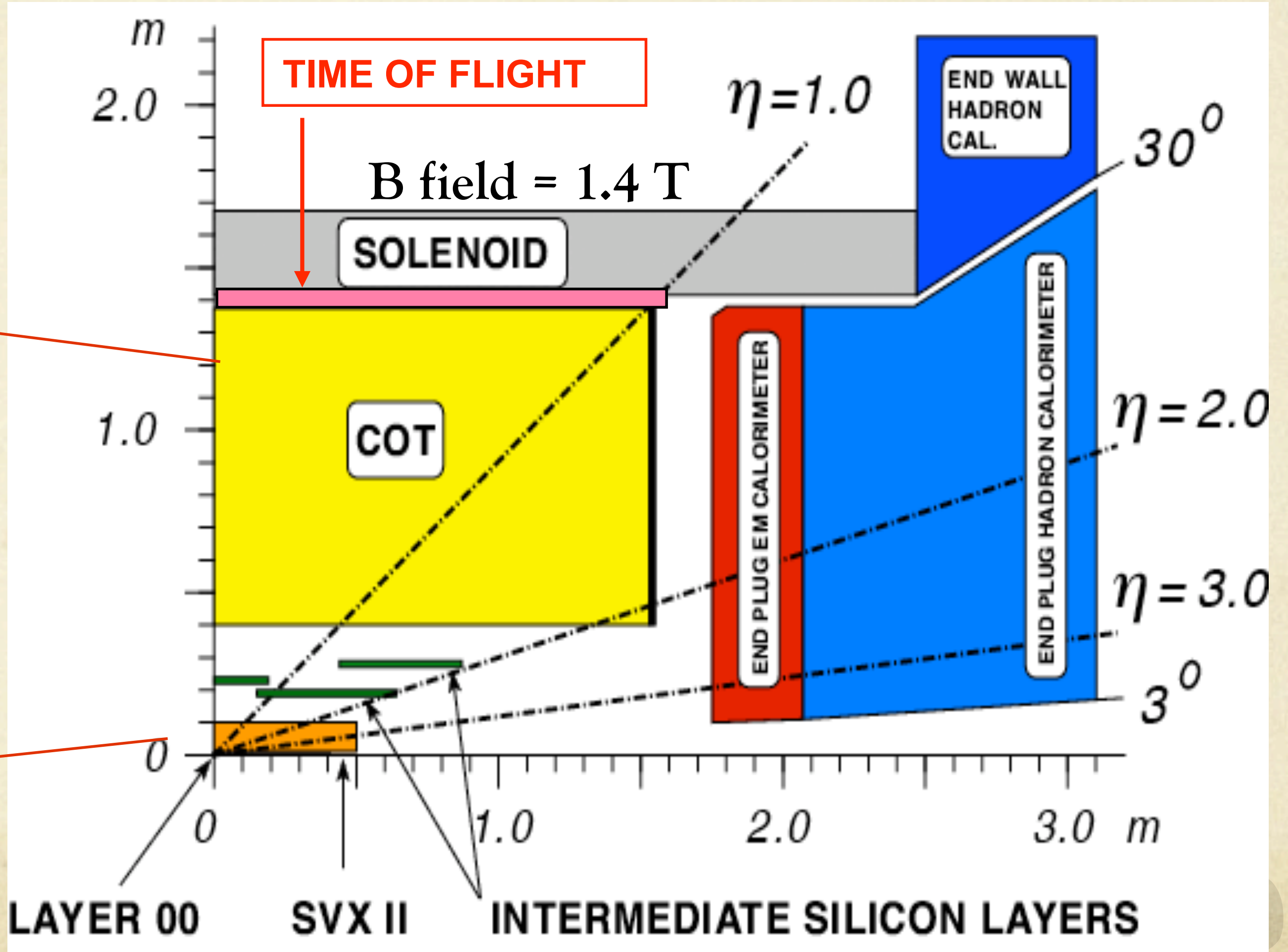
CDF Tracker

Transverse view

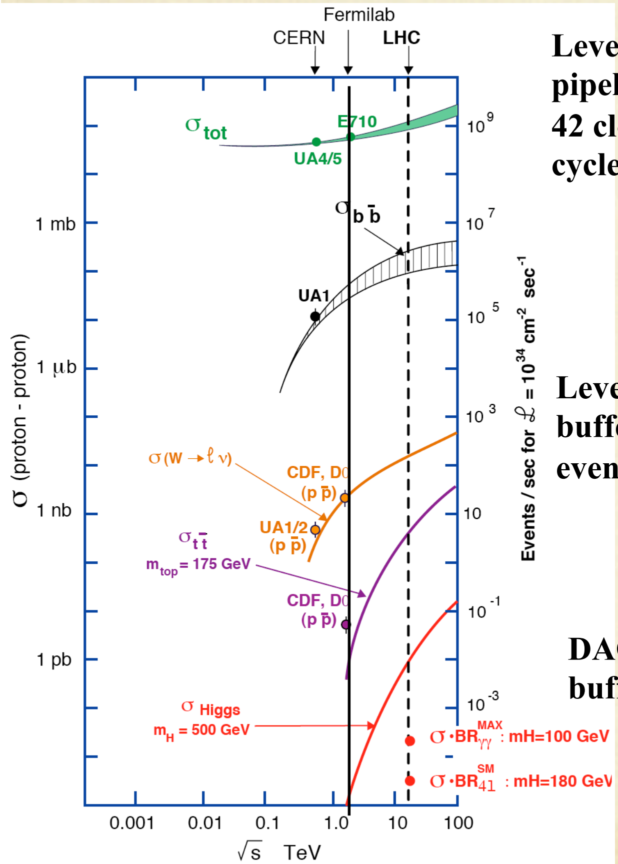


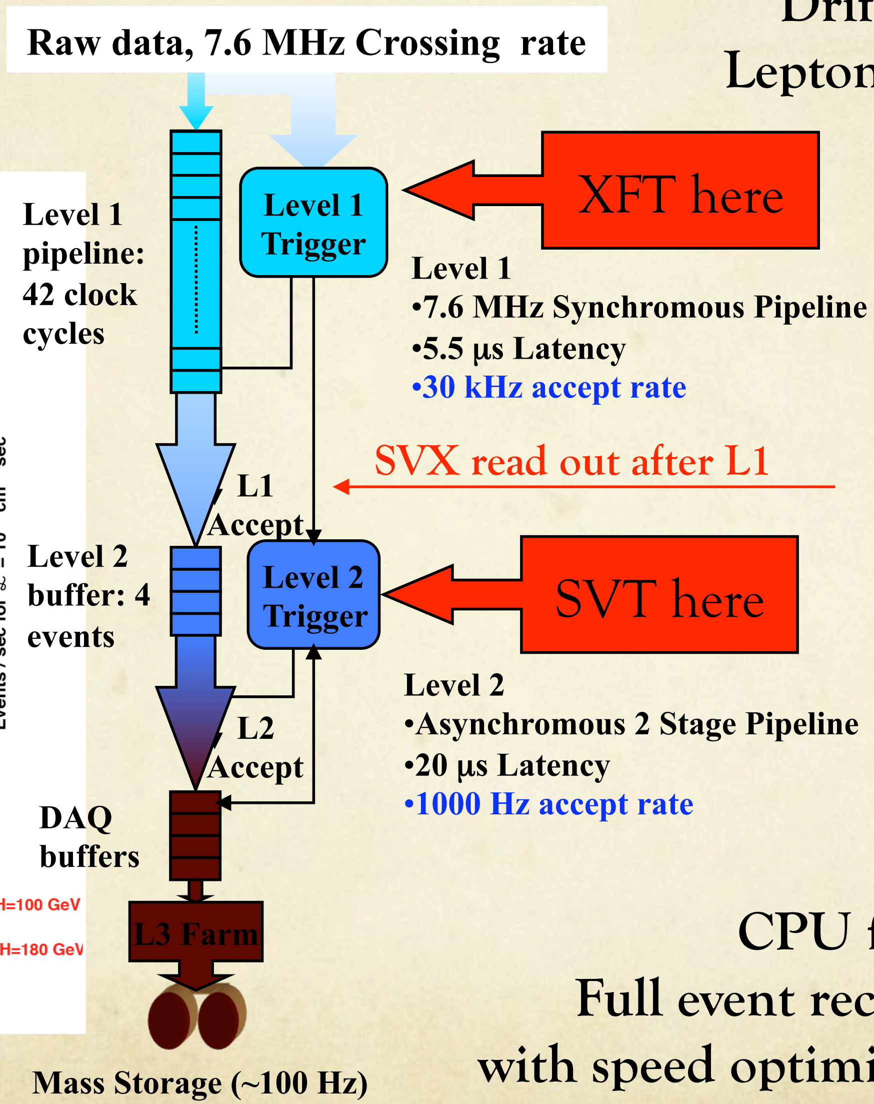


Longitudinal view



CDF Trigger Architecture



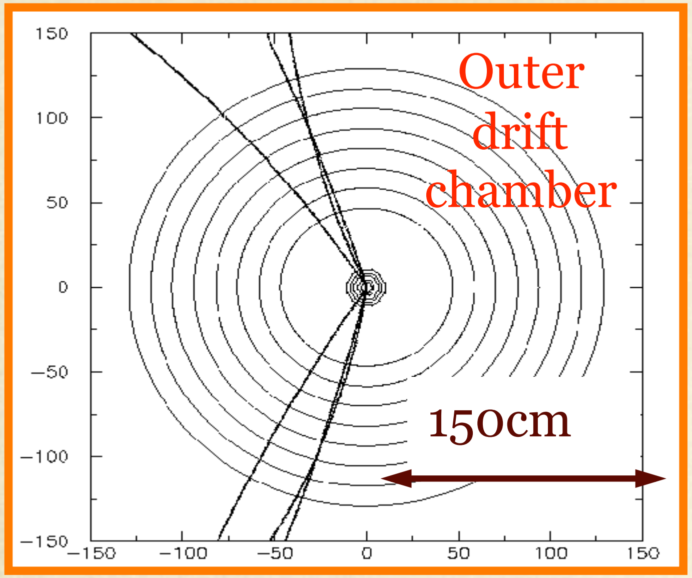


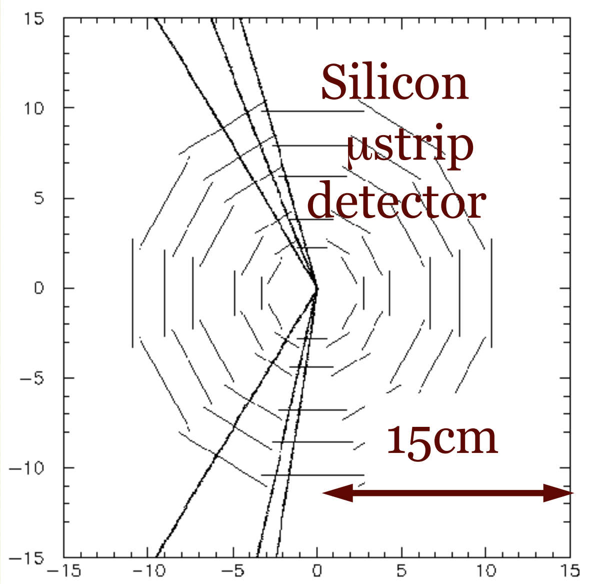
Drift chamber tracking
Lepton reco/track matching
...

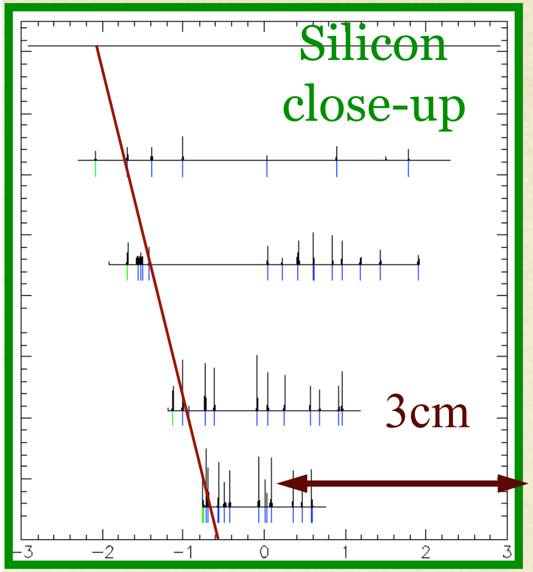
Silicon tracking
Secondary vertex selection
...

CPU farm
Full event reconstruction with speed optimized offline code

SVT Operating principle





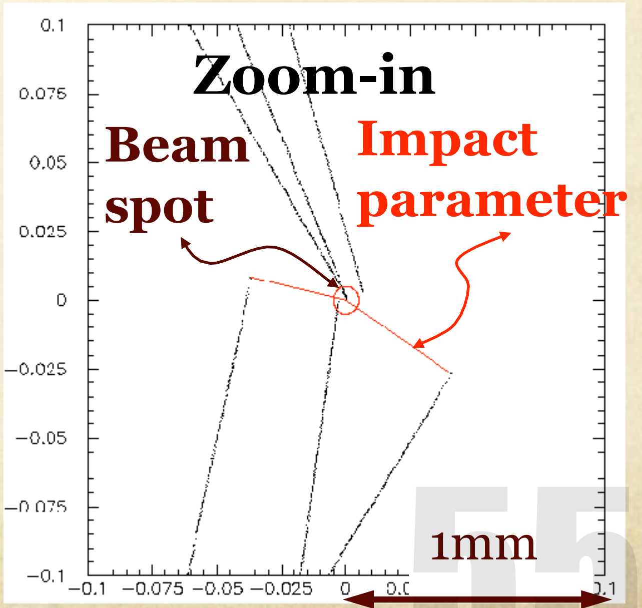


Input (every Level 1 accept):

- XFT trajectories
- silicon pulse height for each channel

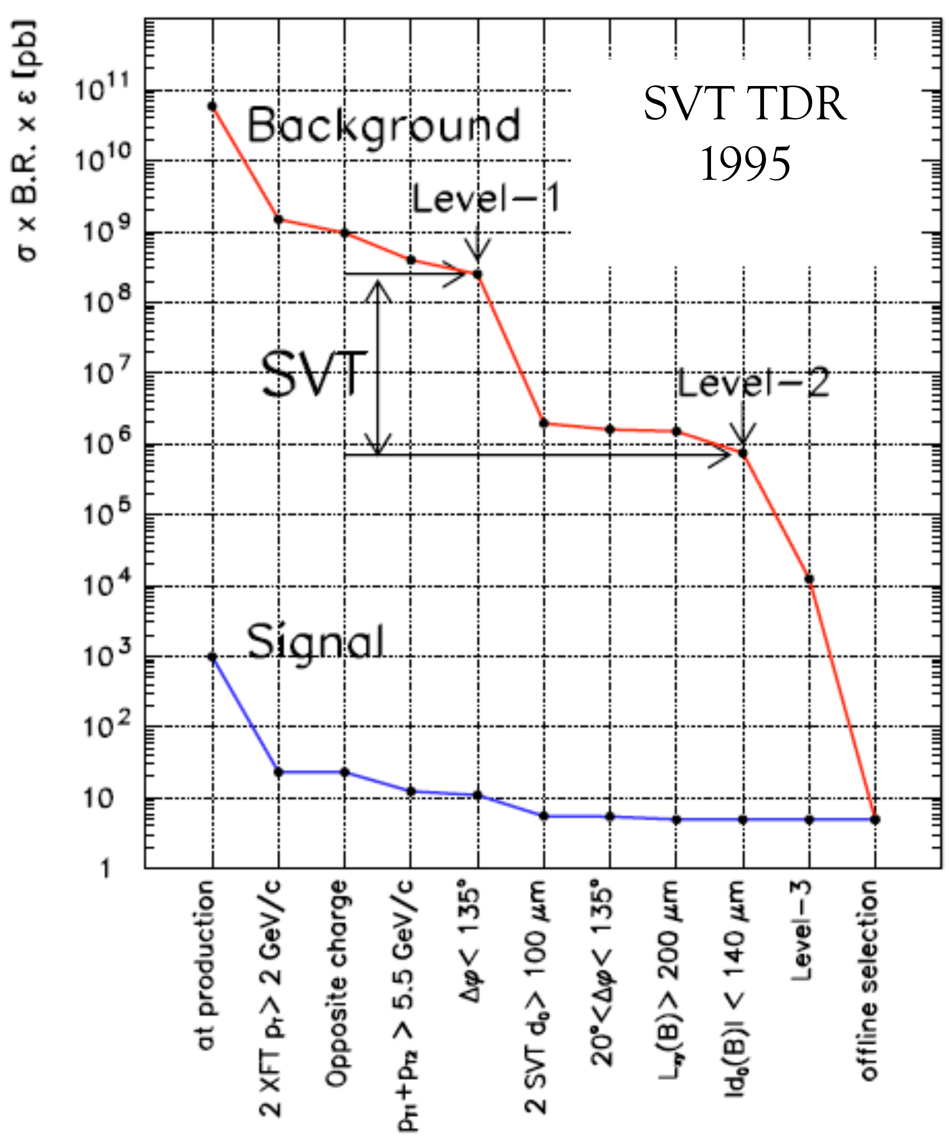
Output (about 20 microseconds later):

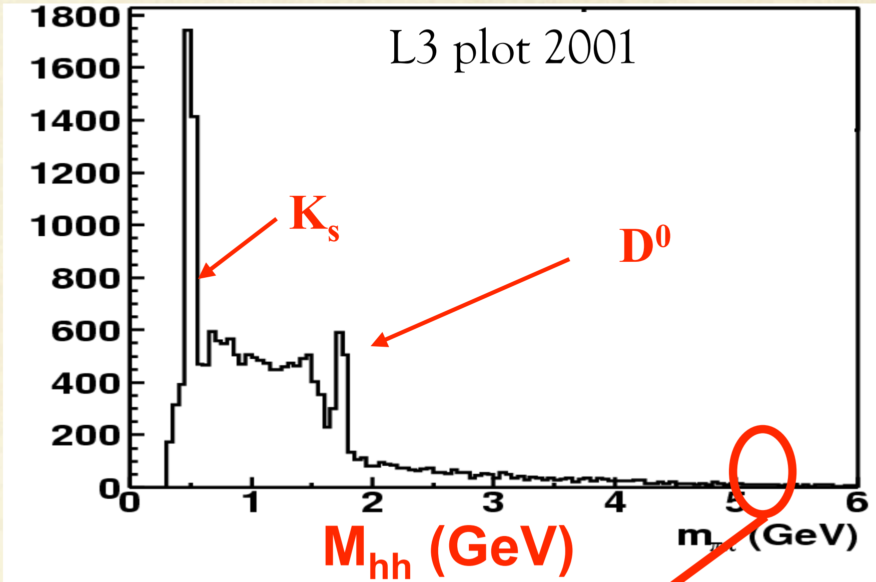
- trajectories that use silicon points
- r-ϕ tracks
- impact parameter: σ(d)=35 μm

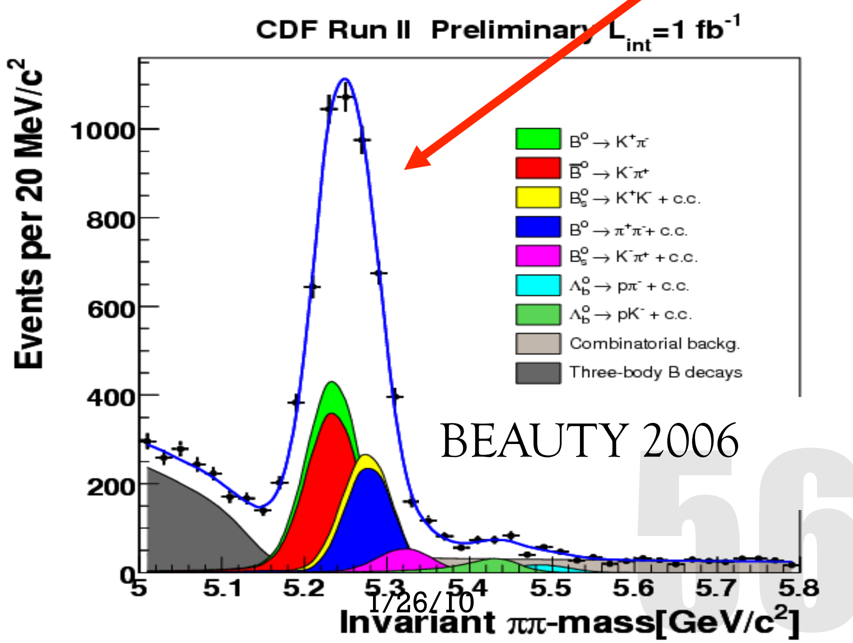


$B^0 \rightarrow$ had + had Trigger

The SVT advantage: 3 orders of magnitude





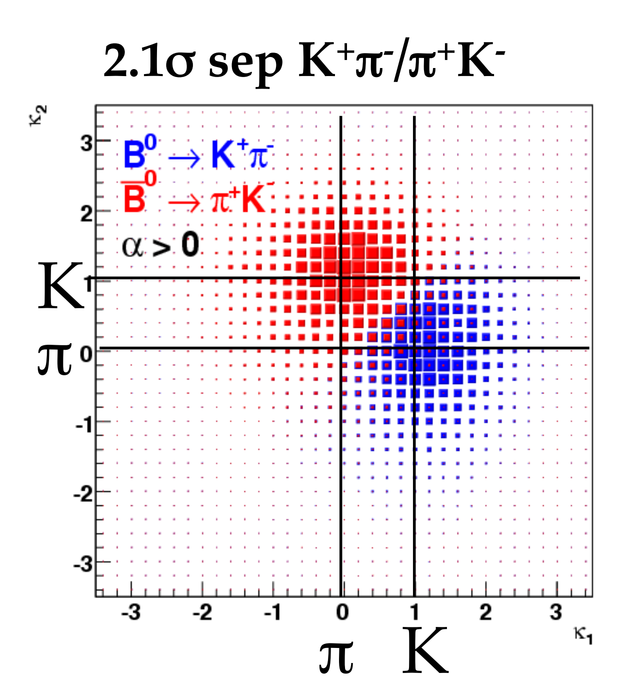


Introducing Kaonness

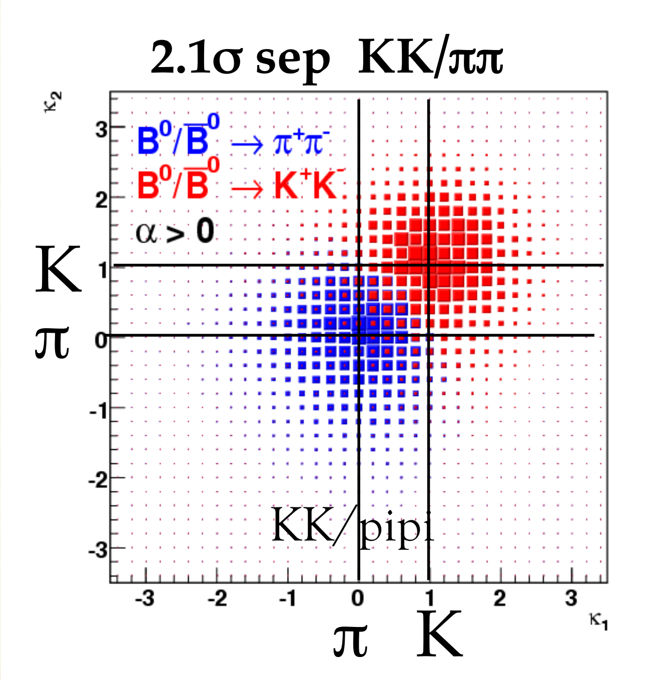
(almost p_T-independent for K and pi)

$$\kappa = \frac{dE/dx_{\rm obs} - dE/dx_\pi}{dE/dx_K - dE/dx_\pi}.$$

Crucial to measure A_{CP}

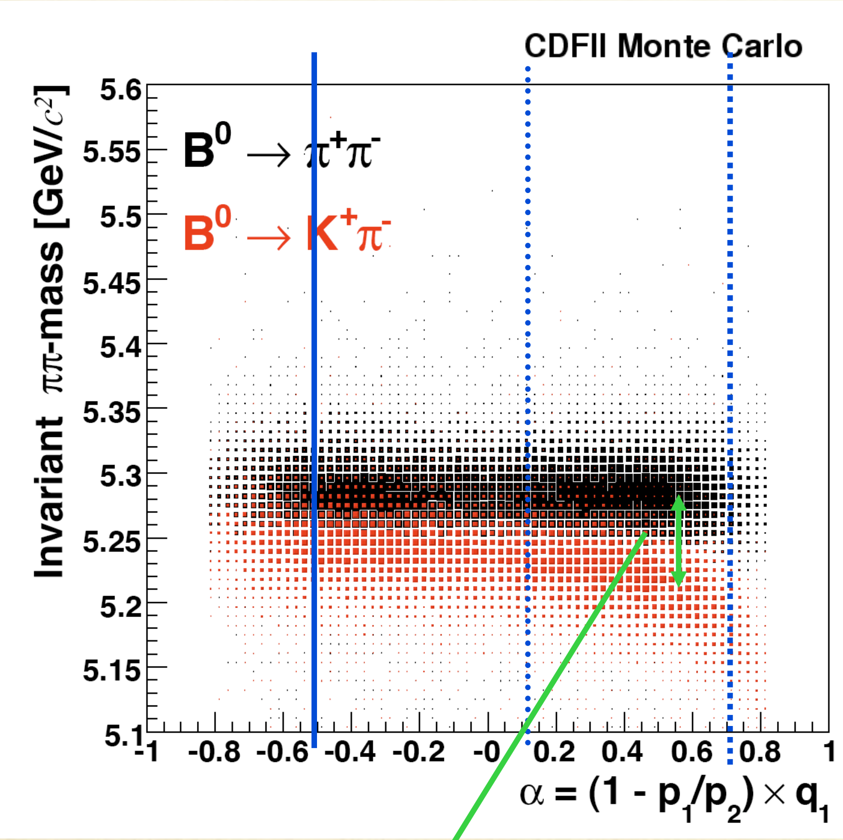


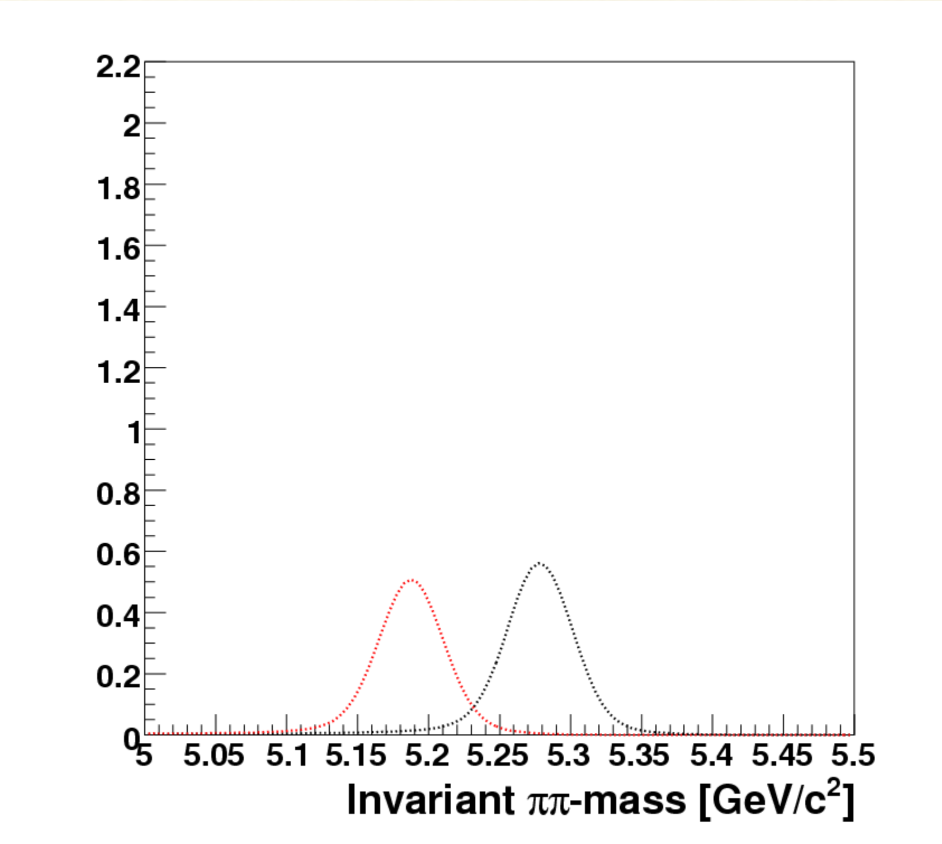
Crucial to measure BR($B^0_s \to K^+K^-$)



This is the first CDF analysis to use the PID in a Likelihood fit.

Kinematics at work: $B^0 \rightarrow K^+\pi^-$ vs $B^0 \rightarrow \pi^+\pi^-$





analytical function of momenta
$f(\alpha, p_{tot})$

Putting it all together

Unbinned ML fit using 5 observables

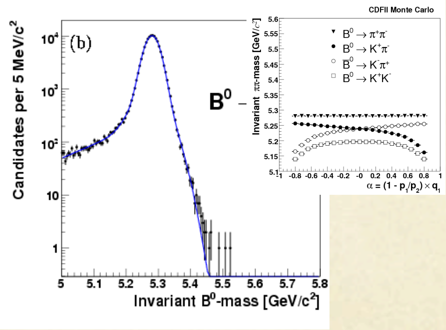
fraction of j^{th} mode, to be determined by the fit

$$\mathscr{L}(\vec{\theta}) = \prod_{i=1}^{N} \mathscr{L}_i(\vec{\theta})$$

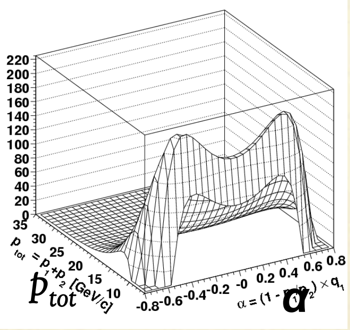
$$\mathscr{L}_i(\vec{\theta}) = (1-b)\sum f_j \mathscr{L}_j^{\text{sign}} + b\mathscr{L}^{\text{bckg}}$$

$$\mathscr{L}^{\text{sig}} = \sum_{j=1}^{s} f_j \cdot \boxed{\wp_j^{m}(m_{\pi\pi}|\alpha, p_{tot})} \cdot \boxed{\wp_j^{p}(\alpha, p_{\text{tot}})} \cdot \boxed{\wp_j^{\text{PID}}(\kappa_1, \kappa_2|\alpha, p_{\text{tot}})},$$

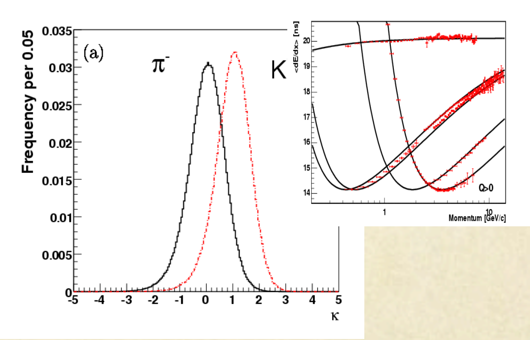
mass term



momentum term



PID term

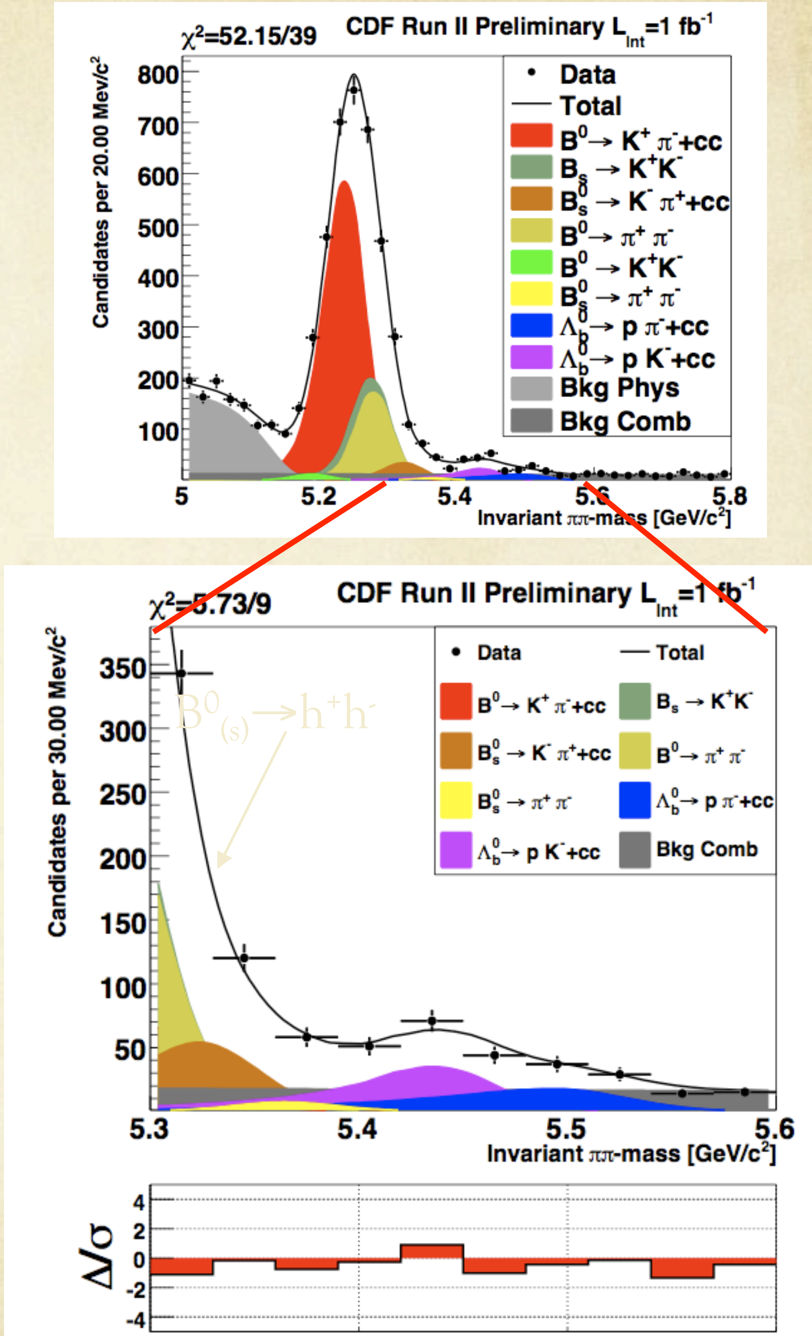


Signal shapes: from MC and analytic formula
Background shapes: from data sidebands

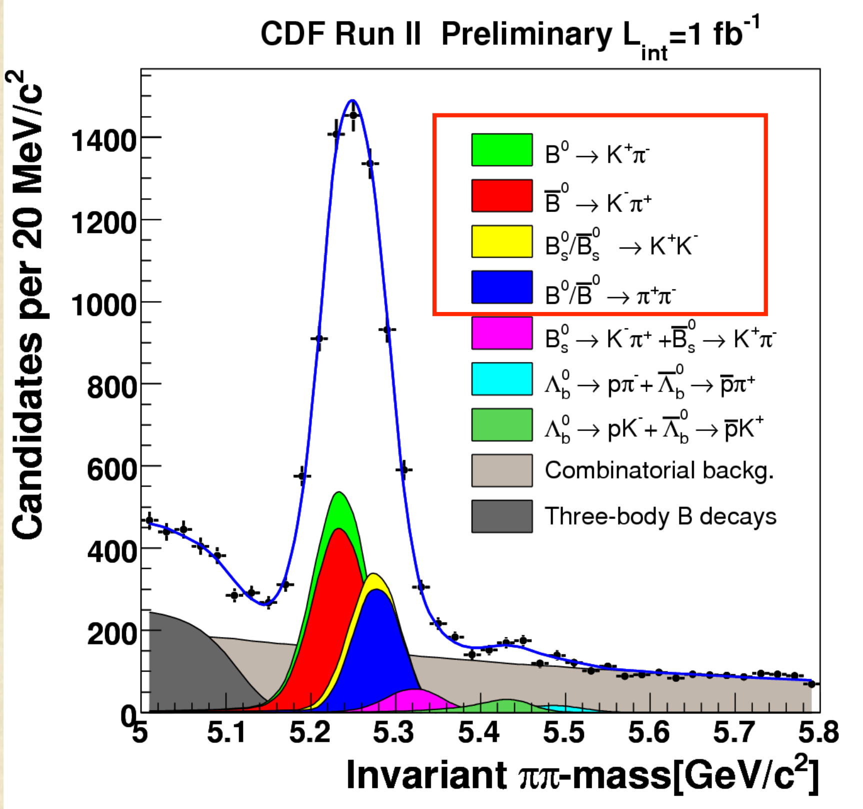
sign and bckg shapes from
$D^0 \to K^-\pi^+$

$\Lambda^0_b \to ph^-$ decays

- $\Lambda^0_b \to ph^-$ amazing "background" of $B^0_{(s)} \to h^+h^-$.
  - First insight to dynamics of b-baryon charmless decays.
  - CPV may reach significant size O(10%) in SM.
- BR/A_{CP} needed additional work with respect to standard B→hh analysis:
  - Λ^0_b p_T spectrum is different from $\bar{B}$
  - Λ^0_b polarization modifies kinematics
  - Evaluation of p/K, p/π and p/p efficiencies due to the presence of a proton in the final state.
- Additional cut on $p_T(\Lambda^0_b)$>6GeV/c is needed because it has been measured in CDF only above this threshold.



Results on "large" modes



B^0 yields comparable to e^+e^-
4045 ± 84 $B^0 \to K^+\pi^-$

3.5σ

$$A_{CP}(B^0 \to K^+\pi^-) = -0.086 \pm 0.023(stat.) \pm 0.09(syst.)$$

Goal with Full Run II statistics ~1%

In agreement with e^+e^- experiments:

$$BaBar(467 MB\overline{B}) \Rightarrow A_{CP} = -0.107 \pm 0.016^{+0.006}_{-0.004}$$
$$Belle(532 MB\overline{B}) \Rightarrow A_{CP} = -0.094 \pm 0.018 \pm 0.008$$

With the same selection performed high precision measurements of:

$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.259 \pm 0.017(stat.) \pm 0.016(syst.)$$

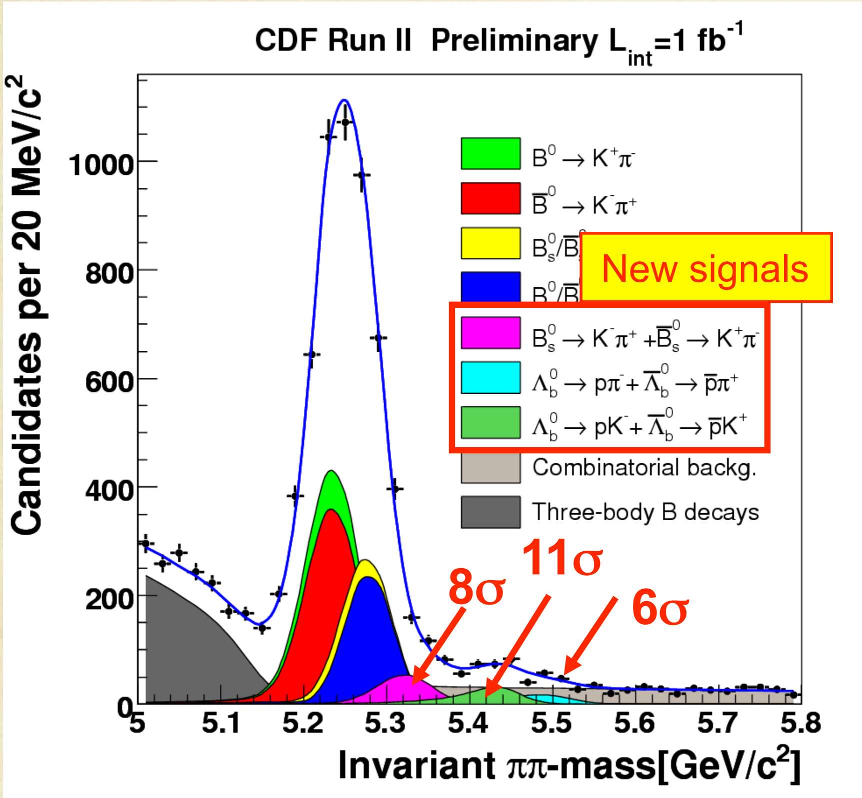
good agreement with e^+e^- experiments, Belle measures 0.26±0.01±0.01 with 449MBBbar.

Largest sample of $B^0_s \to K^+K^-$ ≈1300 ⇒

$$\frac{f_s}{f_d} \times \frac{BR(B^0_s \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} = 0.347 \pm 0.020(stat.) \pm 0.021(syst.)$$

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

First observation of $B^0_s \to K^-\pi^+$



$$\frac{f_s}{f_d} \times \frac{BR(B^0_s \to K^-\pi^+)}{BR(B^0 \to K^+\pi^-)} = 0.071 \pm 0.010(stat.) \pm 0.007(syst.)$$

Using PDG08 inputs:

$$BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.7(stat.) \pm 0.8(syst.)) \times 10^{-6}$$

$BR(B^0_s \to K^-\pi^+)$ theoretical expectations are strongly related to α and γ:
QCDF, pQCD [6-10] $\cdot 10^{-6}$
[NP B675, 333(2003); PRD71,074026 (2005)]
SCET: $(4.9 \pm 1.8) \cdot 10^{-6}$ [PRD74, 014003(2006)]

As a "background" first observation of two baryonic charmless decays: $\Lambda^0_b \to p\pi^-$ (6σ) and $\Lambda^0_b \to pK^-$ (11σ).

BR/DCPV in $\Lambda^0_b \to ph^-$

$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \to p\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.042 \pm 0.007(stat.) \pm 0.006(syst.)$$

$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \to pK^-)}{BR(B^0 \to K^+\pi^-)} = 0.066 \pm 0.009(stat.) \pm 0.008(syst.)$$

BRs are in agreement with SM predictions and exclude BR≈O(10^{-4}) values indicated for R-parity violating Minimal Supersymmetric extensions of the SM model.
[PRD63,056006(2001)]

First DCPV measurements in b-hadrons decays. Statistical uncertainty dominates. Hint of DCPV in baryon decays. Very interesting to pursue with more data.

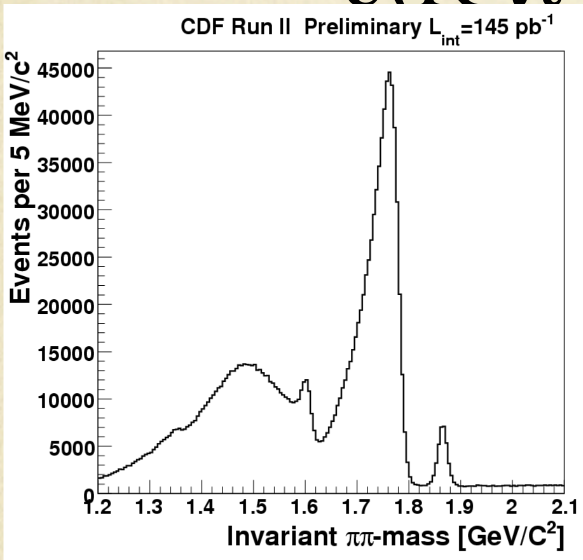
2.1σ

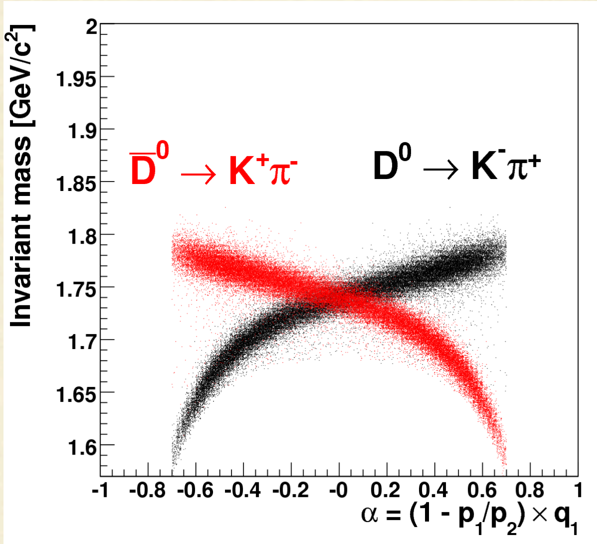
$$A_{CP}(\Lambda_b^0 \to pK^-) = -0.37 \pm 0.17(stat.) \pm 0.03(syst.)$$

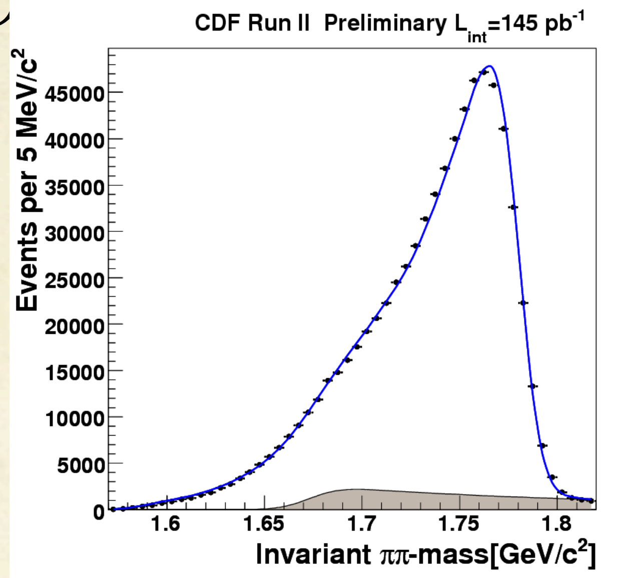
$$A_{CP}(\Lambda_b^0 \to p\pi^-) = -0.03 \pm 0.17(stat.) \pm 0.05(syst.)$$

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph

Detector charge induced CP asymmetry $\varepsilon(K^+\pi^-)/\varepsilon(K^-\pi^+)$ from $D^0 \to K^-\pi^+$







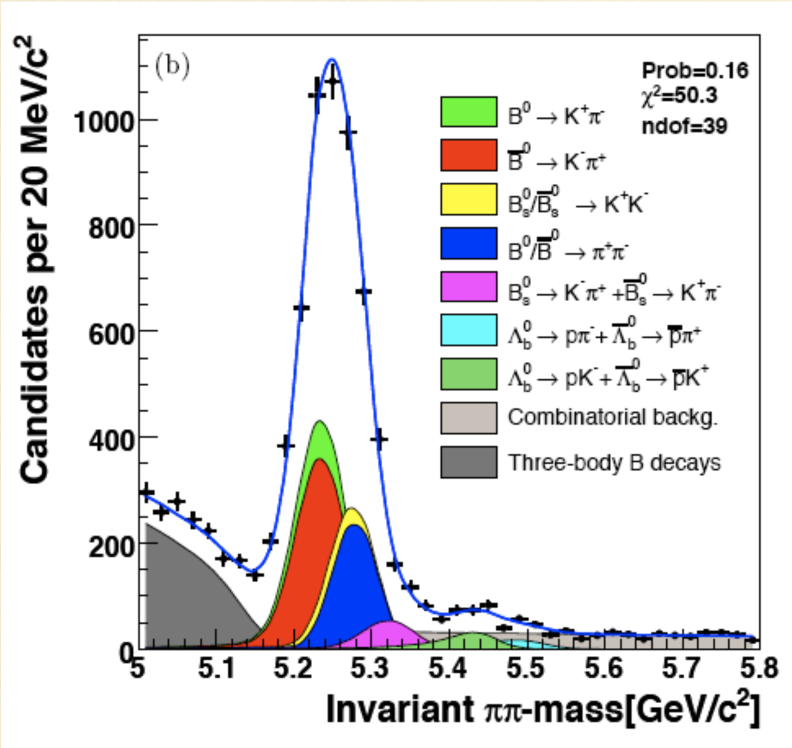
With $\varepsilon(K^+\pi^-)/\varepsilon(K^-\pi^+)$ from MC we obtain:

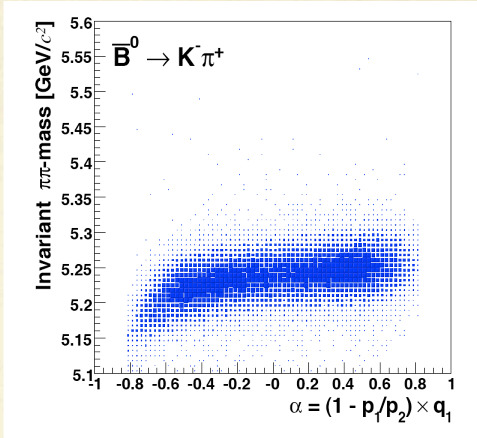
$$A_{CP} = \frac{N_{raw}(\overline{D}^0 \to K^+\pi^-) \cdot \frac{\varepsilon(K^-\pi^+)}{\varepsilon(K^+\pi^-)} - N_{raw}(D^0 \to K^-\pi^+)}{N_{raw}(\overline{D}^0 \to K^+\pi^-) \cdot \frac{\varepsilon(K^-\pi^+)}{\varepsilon(K^+\pi^-)} + N_{raw}(D^0 \to K^-\pi^+)} = -0.00059 \pm 0.00136\ (stat.) \pm 0.0022\ (syst). \tag{22}$$

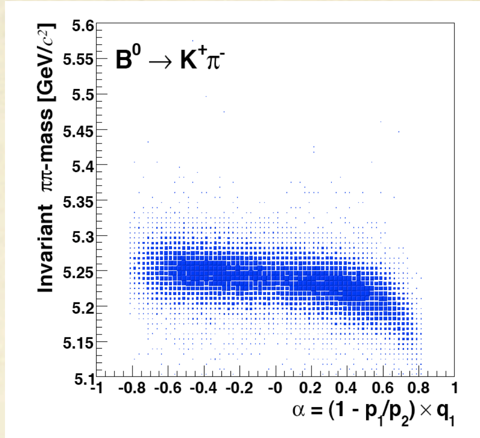
if we assume the $A_{CP}(D^0 \to K^-\pi^+)=0$, we obtain from DATA:

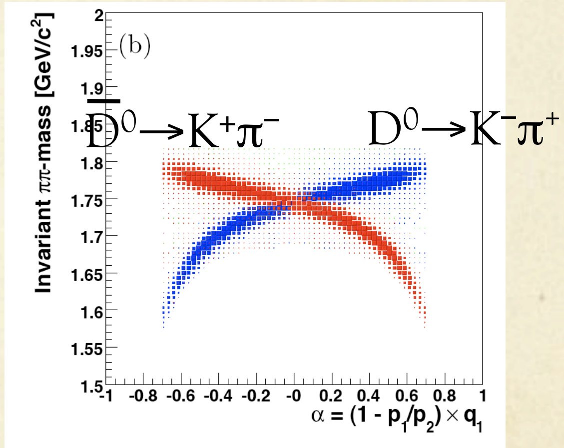
$$\frac{\epsilon(K^-\pi^+)}{\epsilon(K^+\pi^-)} = 0.9837 \pm 0.0027\ (stat.)$$

Disentangling $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$









Inherit $B \to h^+h^-$ technology [*PRL97,211802(2006); PRL103,031801(2009); and PhD. Thesis FERMILAB-THESIS-2007-57*]. A "quasi" perfect separation using just the 2-dim view (β,$m_{\pi\pi}$). Same technique used to extract precise correction for the measurement of CP asymmetry in $B^0 \to K^+\pi^-$. Uncertainty depends on data sample size $\to$ small systematics.

Correcting the raw A_{CP}

$$\mathcal{A}_{CP}(B^0 \to K^+\pi^-) = \frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)} = \frac{\hat{f}_{\overline{B}^0 \to K^-\pi^+} \cdot \frac{\varepsilon(B^0 \to K^+\pi^-)}{\varepsilon(\overline{B}^0 \to K^-\pi^+)} - \hat{f}_{B^0 \to K^+\pi^-}}{\hat{f}_{\overline{B}^0 \to K^-\pi^+} \cdot \frac{\varepsilon(B^0 \to K^+\pi^-)}{\varepsilon(\overline{B}^0 \to K^-\pi^+)} + \hat{f}_{B^0 \to K^+\pi^-}}$$

Only the different K^+/K^- interaction rate with material matters. K^- has a larger hadronic cross section than K^+.

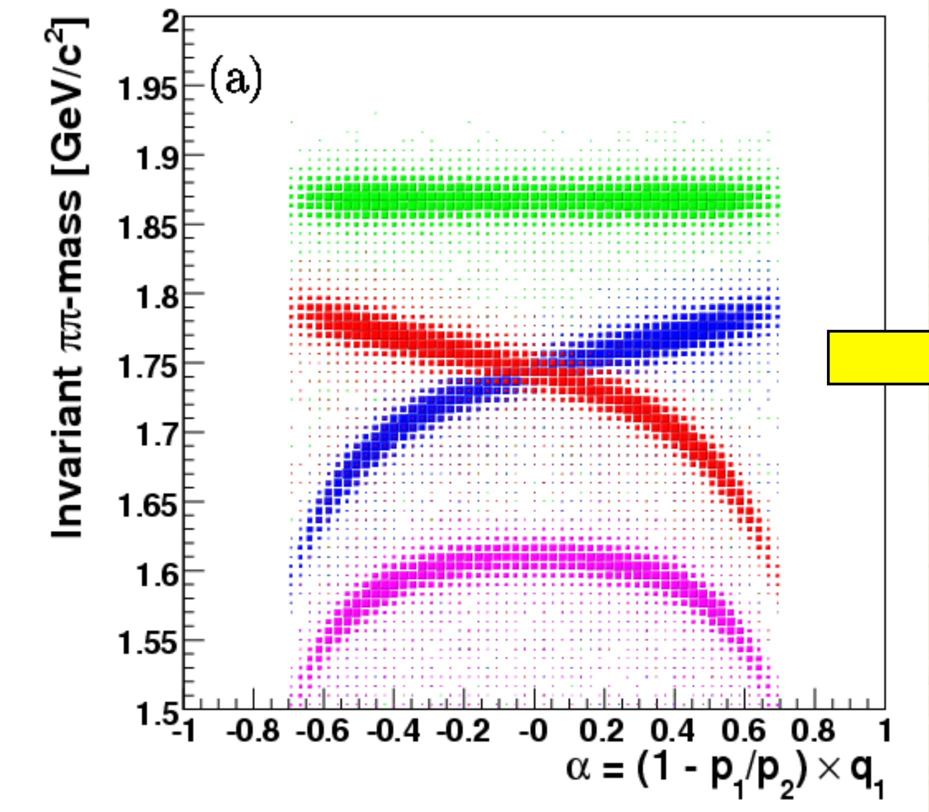
Efficiency ratio $\varepsilon(\overline{B}^0 \to K^-\pi^+)/\varepsilon(B^0 \to K^+\pi^-)$ extracted from the DATA to ensure small systematics.

$$\frac{\varepsilon(\overline{B}^0 \to K^-\pi^+)}{\varepsilon(B^0 \to K^+\pi^-)} = \frac{\varepsilon(B^0_s \to K^-\pi^+)}{\varepsilon(\overline{B}^0_s \to K^+\pi^-)} = 0.9871 \pm 0.0027\ (stat.)$$

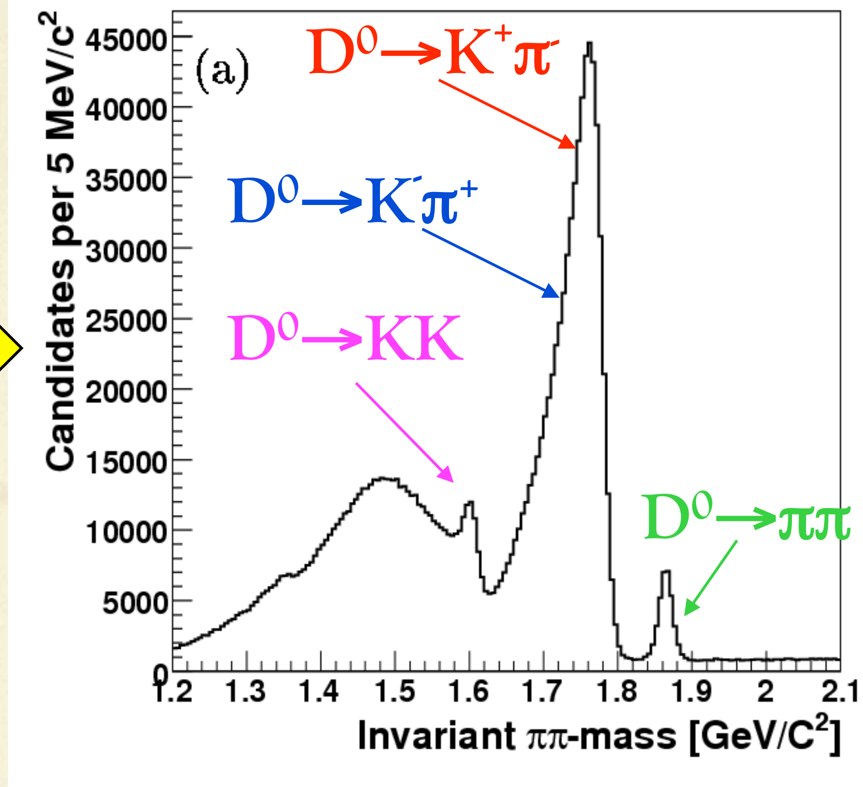
Small (~0.6%) correction. This agrees with an independent evaluation from simulation of CDF detector material. Our estimate is more precise and reliable.

Charge asymmetry measurement

Monte Carlo



≈1M prompt $D^0 \to K^-\pi^+$ decays.



Using the same technique developed for $B^0_{(s)} \to h^+h^-$ analysis (kinematics-only fit $m_{\pi\pi}$, α, p_{tot}) we extracted the charge asymmetry from:

$$\frac{\mathcal{B}(\overline{D}^0 \to K^+\pi^-) - \mathcal{B}(D^0 \to K^-\pi^+)}{\mathcal{B}(\overline{D}^0 \to K^+\pi^-) + \mathcal{B}(D^0 \to K^-\pi^+)} = \frac{\hat{f}_{\overline{D}^0 \to K^+\pi^-} \cdot \frac{\varepsilon(D^0 \to K^-\pi^+)}{\varepsilon(\overline{D}^0 \to K^+\pi^-)} - \hat{f}_{D^0 \to K^-\pi^+}}{\hat{f}_{\overline{D}^0 \to K^+\pi^-} \cdot \frac{\varepsilon(D^0 \to K^-\pi^+)}{\varepsilon(\overline{D}^0 \to K^+\pi^-)} + \hat{f}_{D^0 \to K^-\pi^+}} \ll 10^{-3}$$

Cuts optimization

- Simultaneous measurement of many different observables $A_{CP}(B^0 \rightarrow K\pi)$, $BR(B^0 \rightarrow \pi\pi)$, $BR(B^0_s \rightarrow KK)$, $BR(B^0_s \rightarrow K\pi)$ ....
- High precision measurements for large modes:
  - $B^0 \rightarrow K\pi$, $B^0 \rightarrow \pi\pi$, $B^0_s \rightarrow KK$.
- Discovery measurements for rare modes:
  - $B^0 \rightarrow KK$, $B^0_s \rightarrow \pi\pi$, $B^0_s \rightarrow K\pi$, $\Lambda^0_b \rightarrow pK$, $\Lambda^0_b \rightarrow p\pi$.
- Each measurement requires individual set of cuts aimed to minimize its statistical uncertainty σ.
- IDEA: optimization using a score function $\sigma(S,B)$ which is an approximation of the statistical uncertainty of each observables. S from MC, B from data side bands. $\sigma(S,B)$ determined from actual uncertainties observed in analysis of MC samples, and parameterized by an analytically-inspired model.

Score function

Observables from un-binned Maximum Likelihood fit. A standard analytic estimate of the best possible resolution from a Likelihood fit is the Minimum Variance Bound (MVB):

MVB

$$cov(\mu_i, \mu_j) = \left\{ -E\left[\frac{\partial logL}{\partial\mu_i\partial\mu_j}\right]\right\}^{-1}_{ij}$$

Covariance Matrix μ_i = parameter i[th]

Score function, S signal from MC, B background from DATA side bands

B→hh case

$$\sigma(S, \frac{B}{S}) = \frac{1}{\sqrt{S}}\sqrt{z + w\left(\frac{B}{S}\right)}$$

This is obtained as an approximation of the expression of the MVB for a likelihood fit of a peak over a background.

Better than $S/\sqrt{(S+B)}$:

- it is the right thing (resolution for each individual measurement)
- unambiguous (does not depend on an arbitrary choice of a window)

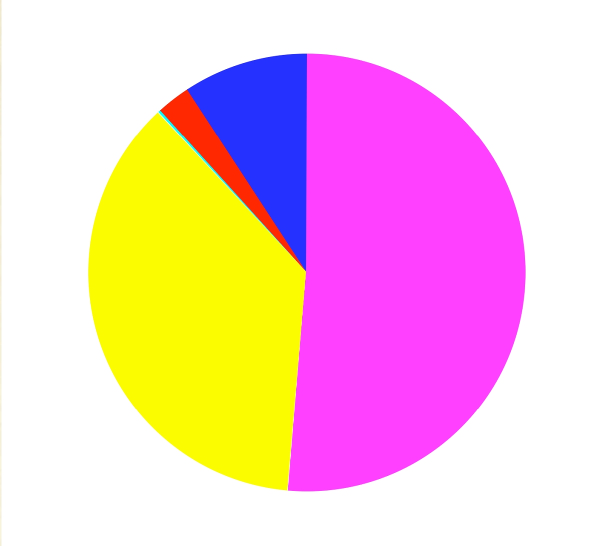
The parameters z and w are determined for each measurement (e.g. $A_{CP}(B^0 \rightarrow K\pi)$, $BR(B^0 \rightarrow \pi\pi)$, ...) using full pseudo-experiments.

Choice of cuts

In practice, only 2 sets of cuts were needed:

- (1) optimize on $A_{CP}(B^0 \rightarrow K^+\pi^-)$ ⇒ Loose cuts
    - good for all three "large modes" ($B^0 \rightarrow K^+\pi^-$, $B^0 \rightarrow \pi^+\pi^-$, $B^0_s \rightarrow K^+K^-$)
- (2) optimize on $B^0_s \rightarrow K^-\pi^+$ ***discovery*** [physics/0308063] ⇒ Tight cuts
    - good for all "rare modes" ($B^0 \rightarrow K^+K^-$, $B^0_s \rightarrow \pi^+\pi^-$, $\Lambda^0_b \rightarrow pK^-$, $\Lambda^0_b \rightarrow p\pi^-$)

Systematics $A_{CP}(B^0 \to K^+\pi^-)$



- dE/dx model (±0.0064);
- Nominal *B*-meson masses (±0.005);
- Background model (±0.003);
- Charge-asymmetries (±0.0014);
- Global mass scale.

Total systematic uncertainty is 0.9%, compare with 2.3% statistical.

Huge sample of prompt $D^0 \to h^+h^-$ (15M).
Kinematic fit using *same code* of $B \to hh$ fit. Direct $A_{CP}(D^0 \to K\pi)$ very small:
⇒ extract from DATA correction for $\varepsilon(K^-\pi^+)/\varepsilon(K^+\pi^-)$ plus any spurious asymmetries.

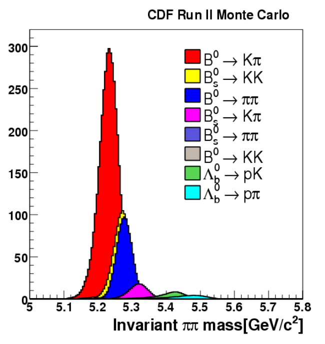
Additional check: measurement of $A_{CP}(D^0 \to K\pi)$ based on dE/dx-only.
Discrepancy with the kinematic fit (≅0.006) within quoted systematics.

Systematics can still decrease with larger calibration samples
Prospects for a runII CDF measurement with **≈1% uncertainty.**

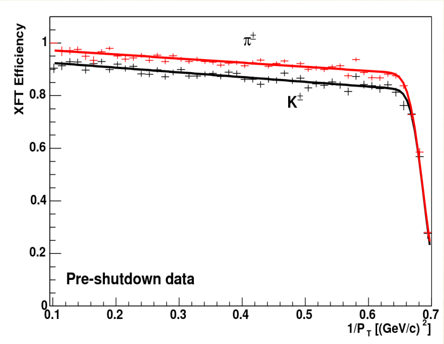
$B^0 \rightarrow \pi^+\pi^- / B^0 \rightarrow K^+\pi^-$ ratio of decay rates

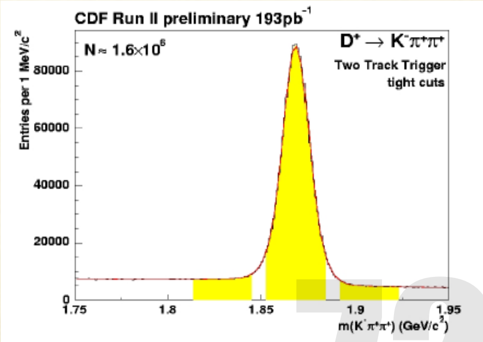
$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = \left.\frac{N(B^0 \to \pi^+\pi^-)}{N(B^0 \to K^+\pi^-)}\right|_{\mathrm{raw}} \cdot \frac{\epsilon_{kin}(B^0 \to K^+\pi^-)}{\epsilon_{kin}(B^0 \to \pi^+\pi^-)} \cdot \frac{c_{XFT}(B^0 \to K^+\pi^-)}{c_{XFT}(B^0 \to \pi^+\pi^-)}$$

Different efficiency of the selection due to kinematical difference between the decays, and different decay-in-flight and interaction probability between K and π. Get from Monte Carlo the ratio of kinematics efficiencies.
~ 3% correction



π ionizes more than K ; this introduces a bias in the trigger on tracks within the drift chamber (XFT). Use data from unbiased legs in $D^+ \to K^-\pi^+\pi^+$ sample.
~ 5% correction





Uniqueness of Charm (I)

- Standard Model (SM)
  - FCNC greatly suppressed
  - even more so for up-type quarks
- New Physics (NP)
  - FCNC might be less suppressed for up-type quarks

SM `background' much smaller for FCNC of up-type quarks
$\rightarrow$ cleaner (not larger) signal:

$$\left[\frac{\text{NP signal}}{\text{ther. SM noise}}\right]_{\text{up-type}} > \left[\frac{\text{NP signal}}{\text{ther. SM noise}}\right]_{\text{down-type}}$$

Uniqueness of Charm (II)

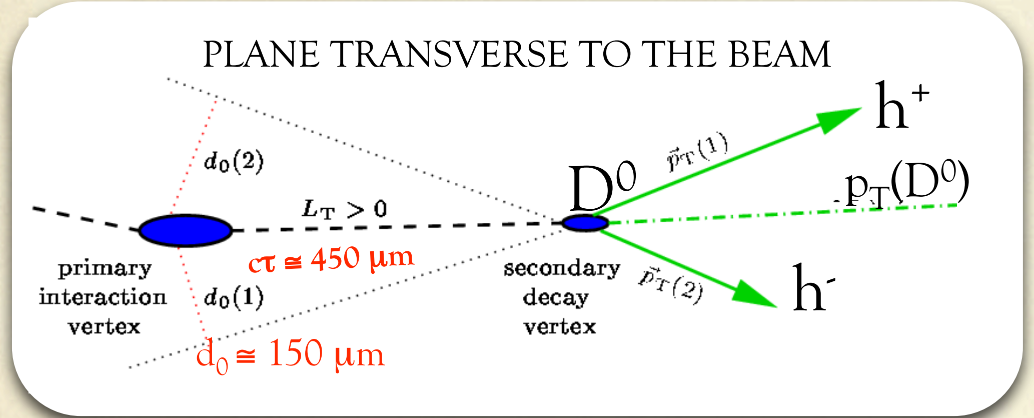
- Charm is the only up-type quark (u, c ,t) allowing full range of probes for NP.
  - top quarks do not hadronize → no T^0 - antiT^0 oscillations
    - hadronization while hard to force under theor. control enhances observability of CP violation
  - no π^0-π^0 oscillations possible
    - particle and anti-particle are identical

Charm transitions are a unique portal for obtaining a novel access to flavor dynamics with the experimental situation being a priori favorable.

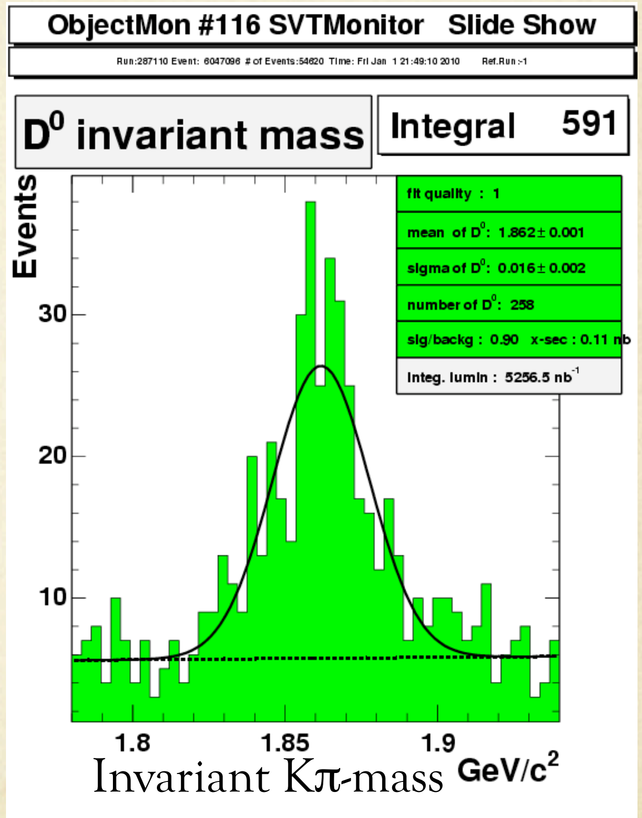
Beauty and Charm at CDFII

- CDFII is a wonderful place for charm physics
  - High production cross section.
  - Efficient and flexible trigger.
  - Excellent vertexing and mass resolution.
  - CP-invariant strong production (p-pbar initial state).
  - Symmetric detector in pseudo-rapidity.
- The result is:
  - world's largest data sample.
  - Precise control of detector-induced charge asymmetries.

$D^0 \to h^+h^-$ (h is for pion or kaon) Trigger Requirements



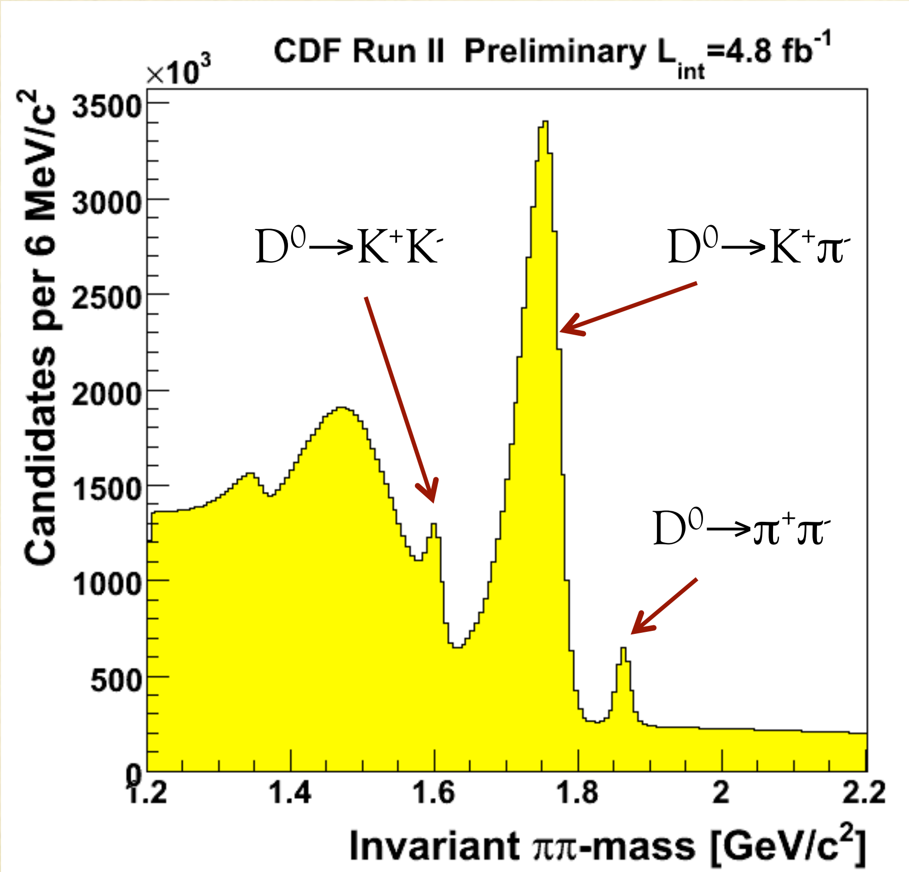
Monitoring



- Two oppositely-charged tracks from a long-lived decay:
  - track's impact parameter 100μm < d_0 < 1mm;
  - *B* transverse decay length L_T > 200 μm;
- Reject light-quark background from jets:
  - transverse opening angle 2°<Δϕ<90°;
  - transverse momentum p_T(track)>2GeV/c ;
  - $p_{T1}+p_{T2}$ >5.5 GeV/c.

Untagged $D^0 \to h^+h^-$ sample

Just trigger confirmation at offline level



No tag required from $D^{*+} \to D^0\pi^+$ decay

$N(D^0 \to \pi^+\pi^-) \approx 1.7\times10^6$

$N(D^0 \to K^+K^-) \approx 4.7\times10^6$

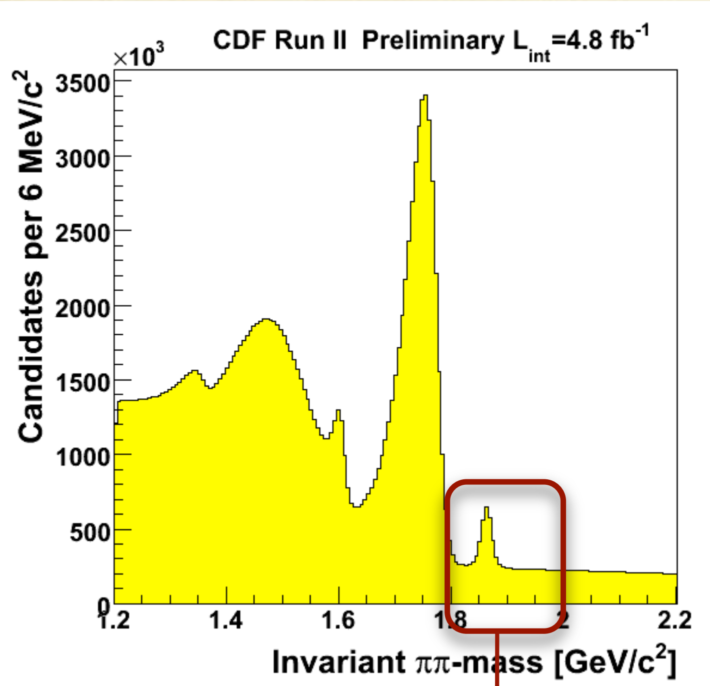
$N(D^0 \to K^-\pi^+) \approx 47\times10^6$

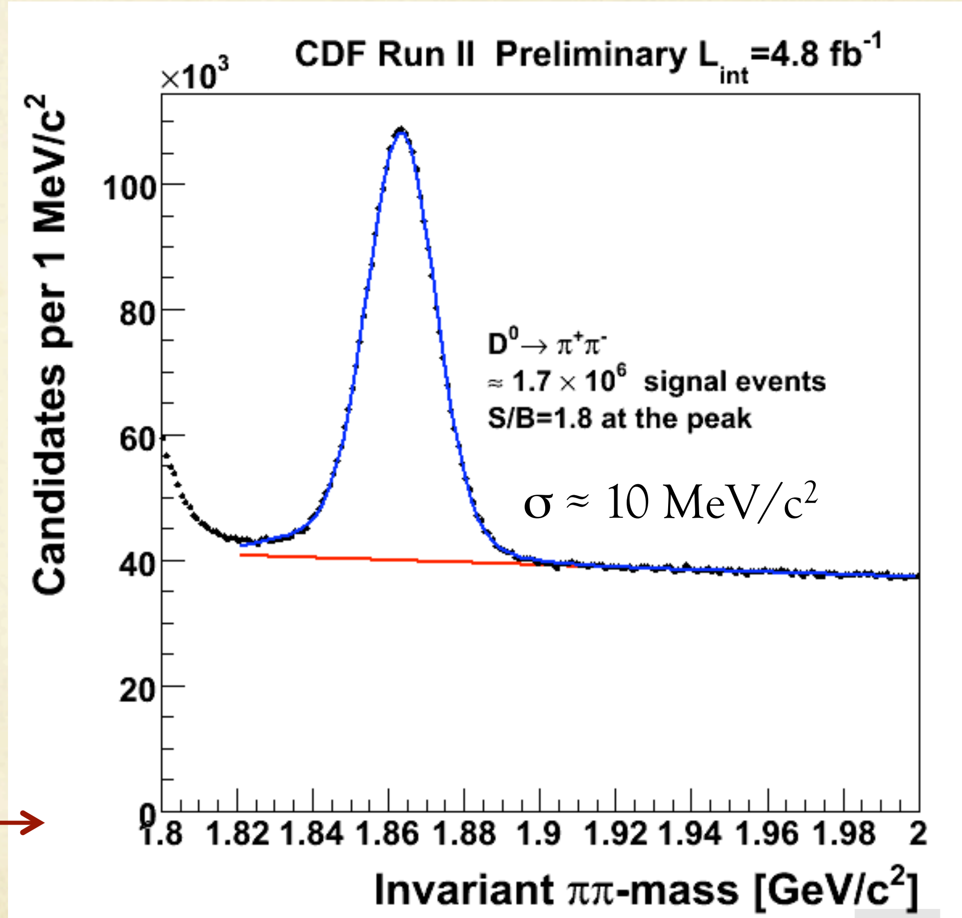
World's largest data sample

Without hadronic trigger in $5fb^{-1}$ just 50 $D^0 \to K^-\pi^+$ (from Minimum Bias)

Note: hadronic trigger not optimized for charm, optimized for B-decays ($B^0_s \to D_s\pi$ and $B \to \pi^+\pi^-$), large room to improve charm acceptance.

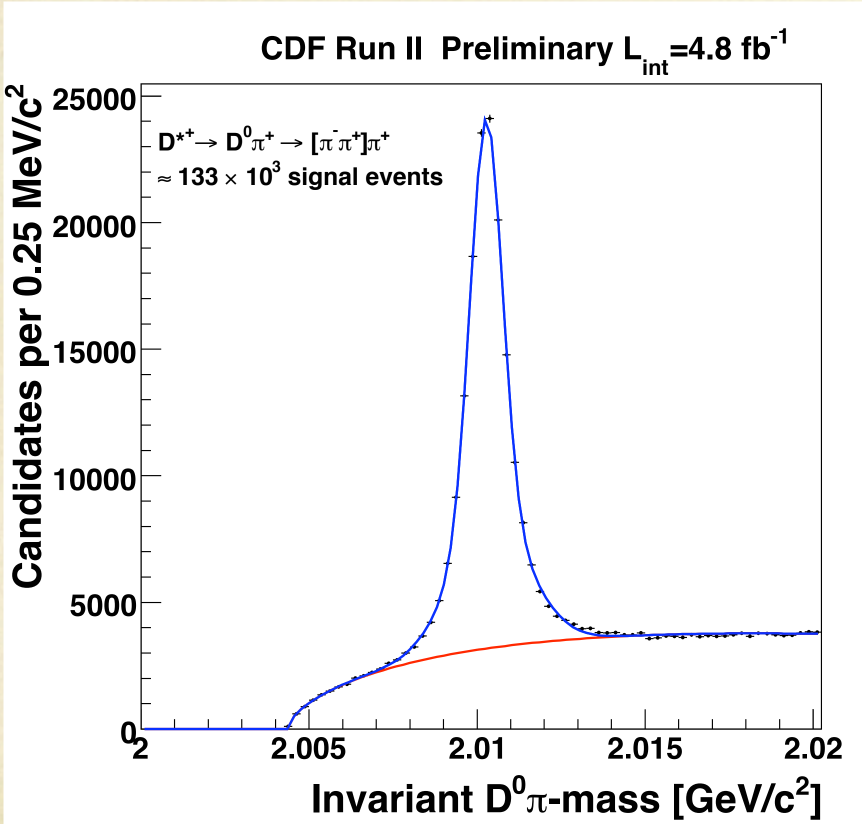
Untagged $D^0 \to \pi^+\pi^-$ (zoom)

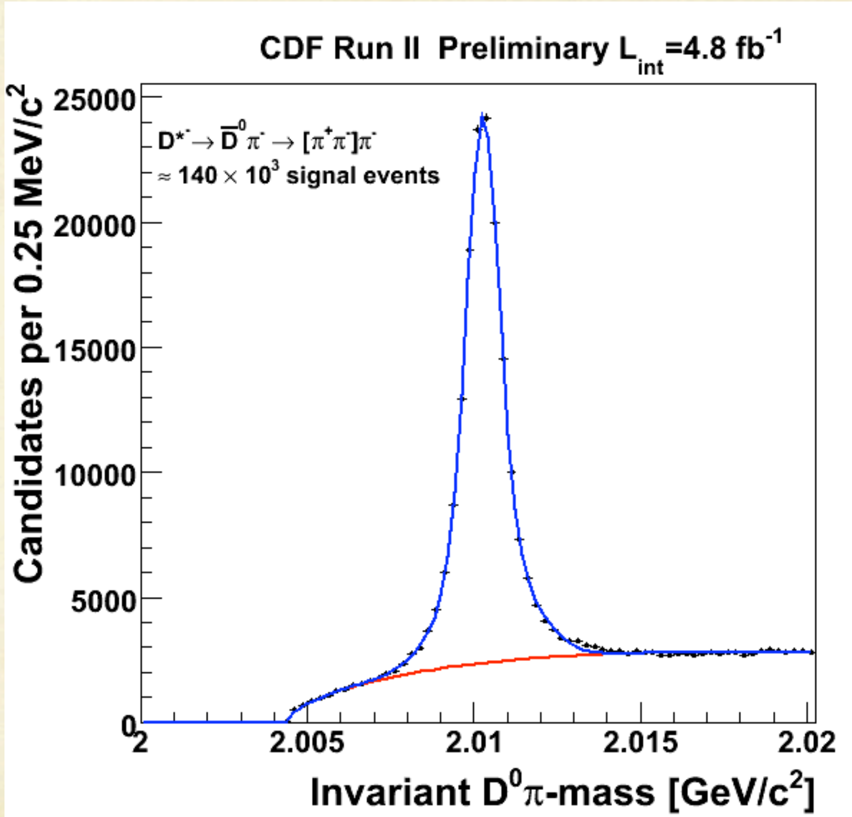




$D^{*+} \to D^0\pi^+ \to [\pi^-\pi^+]\,\pi^+$

Select events with invariant $\pi\pi$-mass in $\pm 3\sigma$ mass window around D^0 nominal mass value



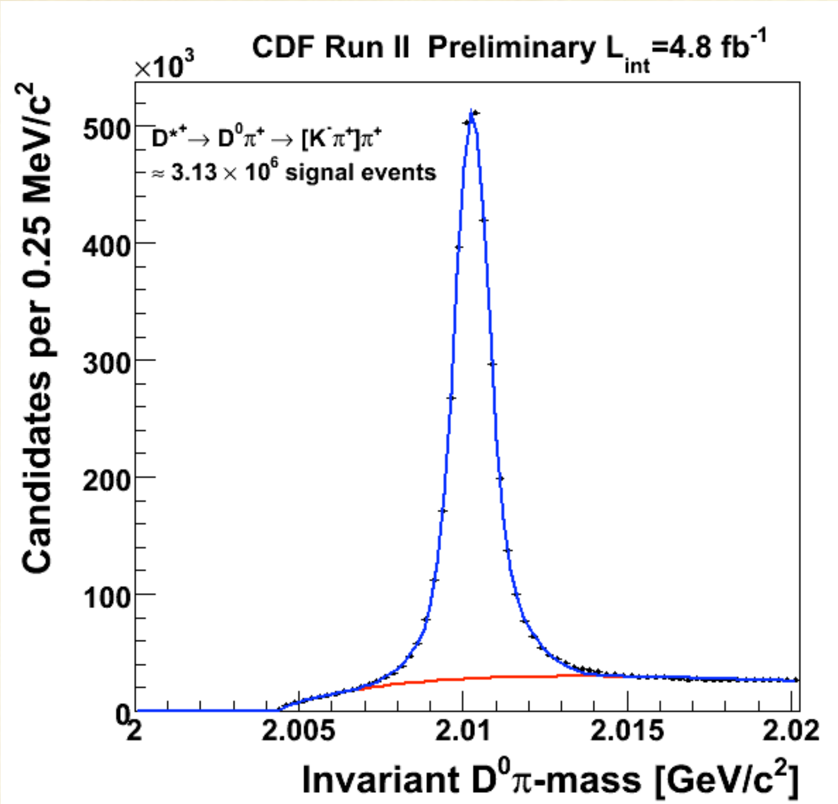


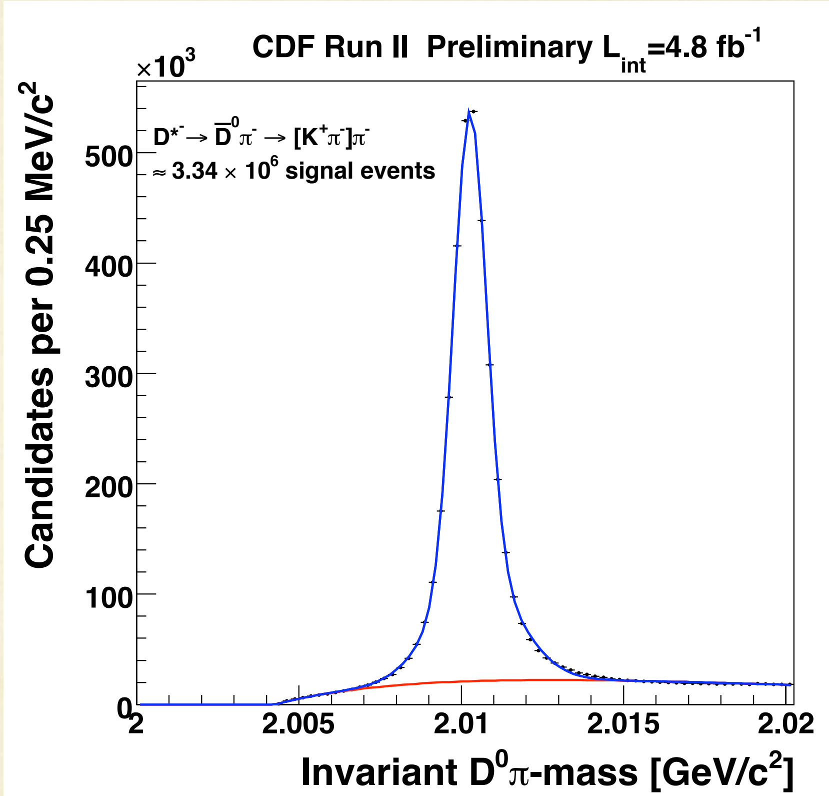
133k $D^{*+} \to D^0\pi^+ \to [\pi^-\pi^+]\pi^+$

140k $D^{*-} \to$ anti$D^0\pi^- \to [\pi^+\pi^-]\pi^-$

$D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\,\pi^+$

Select events with invariant $K\pi$-mass in $\pm 3\sigma$ mass window around D^0 nominal mass value



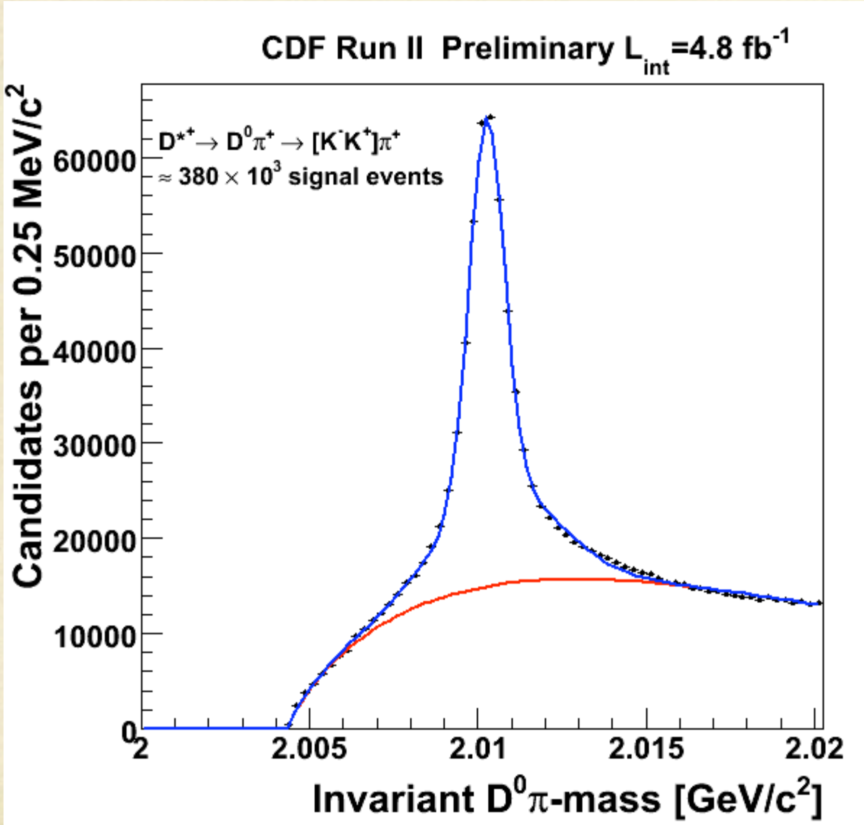


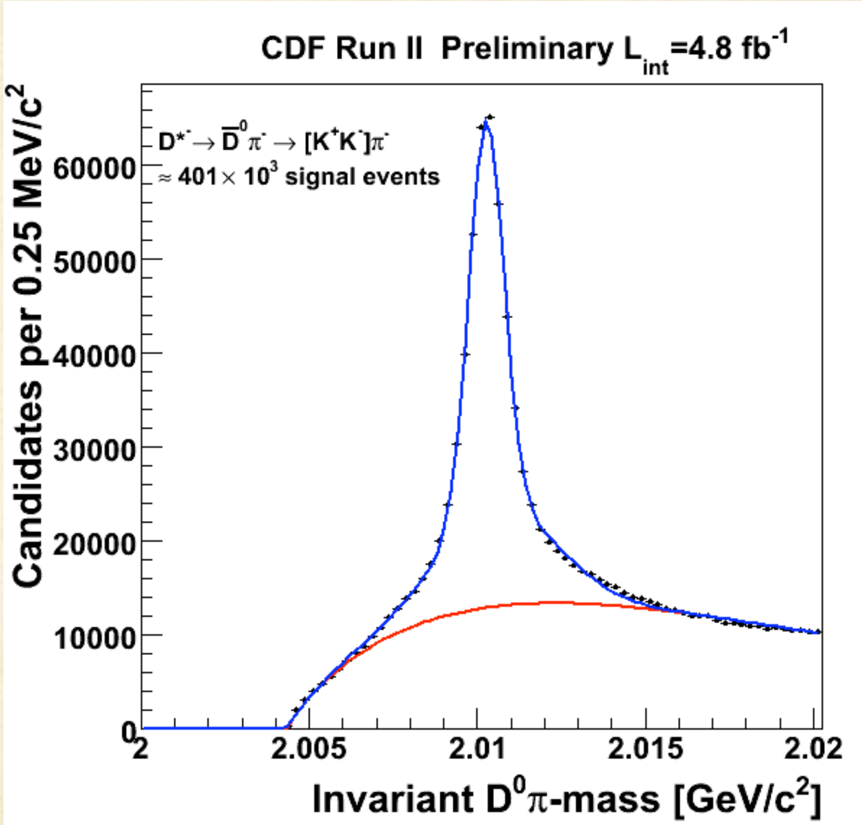
3.13M $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\pi^+$

3.34M $D^{*-} \rightarrow$ anti$D^0\pi^- \rightarrow [K^+\pi^-]\pi^-$

$D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-K^+]\,\pi^+$

Select events with invariant KK-mass in $\pm 3\sigma$ mass window around D^0 nominal mass value





380k $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-K^+]\pi^+$

401k $D^{*-} \rightarrow$ anti$D^0\pi^- \rightarrow [K^+K^-]\pi^-$

Prospects for $A_{CP}(D^0 \to \pi^+\pi^-)$ on 4.8 fb^{-1}

Assuming: $\sigma_N \cong \sigma_{\bar{N}} \cong 1/\sqrt{N} \Rightarrow \sigma_{A_{CP}} = 1/\sqrt{N+\bar{N}}$

Experiment	N $(D^0 \to \pi^+\pi^-)$	$A_{CP}(D^0 \to \pi^+\pi^-)$ (%)
CDF(4.8/fb)	273K	xxx ± 0.19(stat) ± xxx (syst)
Babar (386/fb)	64K	−0.24 ± 0.52(stat) ± 0.22(syst)
Belle(540/fb)	51K	+0.43 ± 0.52(stat) ± 0.12 (syst)

CDF can gain about 25% removing cut on $p_T(\pi_s)$>0.4GeV/c, but larger background to handle. Systematic uncertainty is expected less than 0.1%. CDF is currently taking data.

Prospects for $A_{CP}(D^0 \rightarrow K^+K^-)$ on 4.8 fb^{-1}

Assuming: $\sigma_N \cong \sigma_{\overline{N}} \cong 1/\sqrt{N} \Rightarrow \sigma_{A_{CP}} = 1/\sqrt{N+\overline{N}}$

Experiment	N $(D^0 \rightarrow K^+K^-)$	$A_{CP}(D^0 \rightarrow K^+K^-)$ (%)
CDF(4.8/fb)	781K	xxx ± 0.11(stat) ± xxx (syst)
Babar (386/fb)	129K	0.00 ± 0.34(stat) ± 0.13(syst)
Belle(540/fb)	120K	−0.43 ± 0.30(stat) ± 0.11 (syst)

CDF can gain about 25% removing cut on $p_T(\pi_s)$>0.4GeV/c, but larger background to handle.
Systematic uncertainty is expected less than 0.1%. CDF is currently taking data.

dE/dx

A few words on dE/dx calibration

- Use triggered pion/kaon sample from: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\pi^+$
    - Calibration sample has $p_T > 2$GeV/c only, Purity > 99%
- Ideally, dE/dx depends only on momentum:
    - extensive search of detector-induced dependences in several kinematic/ environmental quantities: ϕ_0, η, time, luminosity, #of drift chamber hits,…
- Determine hierarchy of dE/dx dependences and find which dependences are factorisable
- Flatten dE/dx in each parameter space
- Determine and parameterise "expected dE/dx" curve
- Store correction factors, universal curves and dE/dx residual shapes.

Correction Parameters

- Study of dE/dx dependences lead to corrections dependent on 6 parameters:
  - ϕ_0 [independent correction]
  - η [independent correction]
  - #COT hits (H), time (t), secance (#track intersections S), luminosity. [4-D simultaneous correction]

$$dE/dx = f(\phi_0) \times h(\eta|p) \times g(\mathcal{H}, \mathcal{L}, t, \mathcal{S}),$$

independent

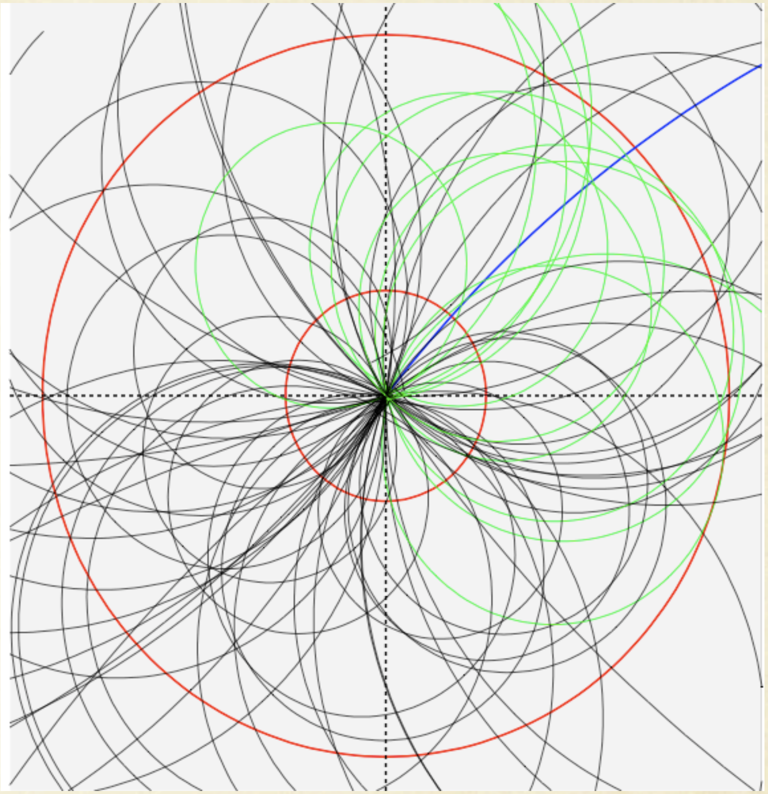
Conditional probability of momentum

4-dim correction

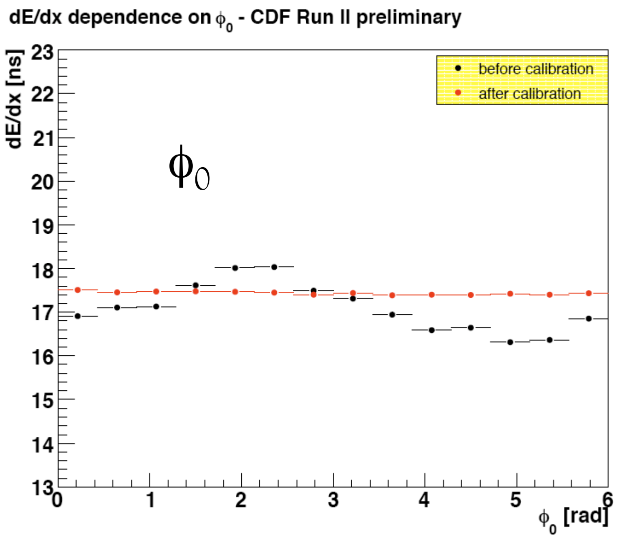
Secance

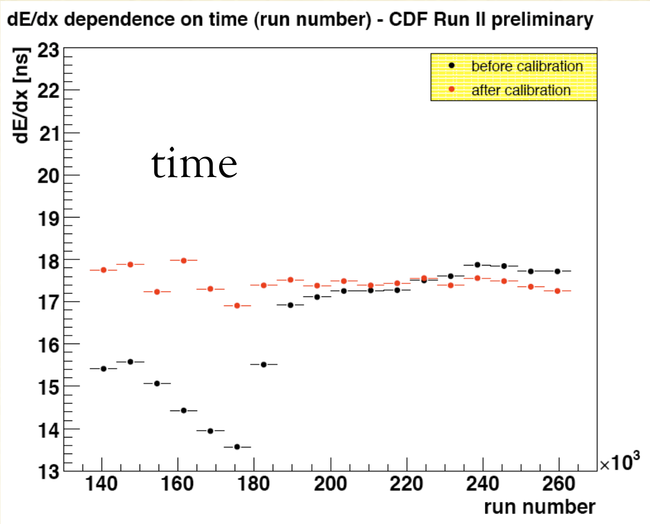
Since the COT wires have no longitudinal segmentation, any extra hit that is axially close to the track of interest can contribute to the dE/dx of the track, introducing a dependence on hit-density.

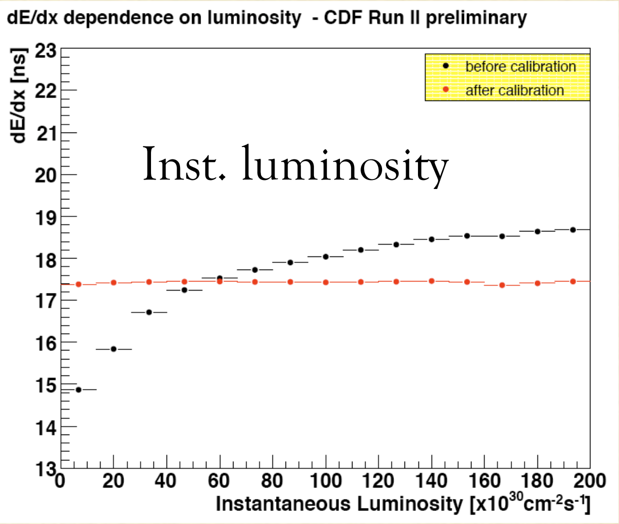
Track-density is estimated using the secance (S) observable, defined, for each track, as the number of axially-intersecting tracks within the COT volume.

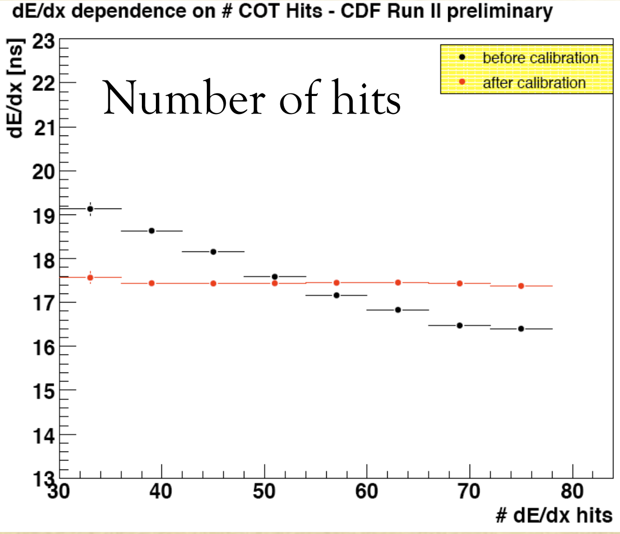


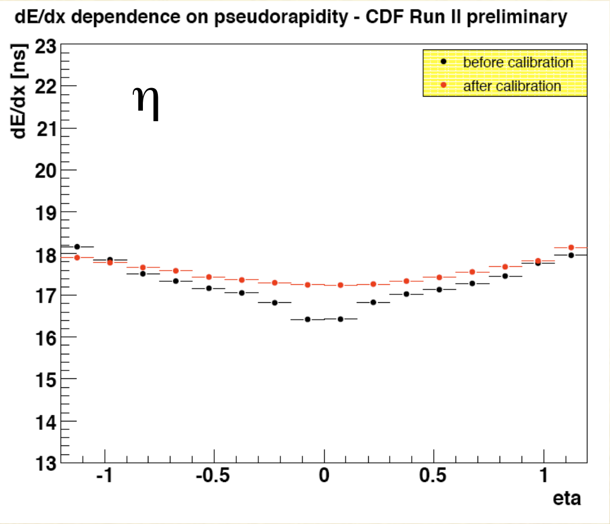
dE/dx Corrections: Results

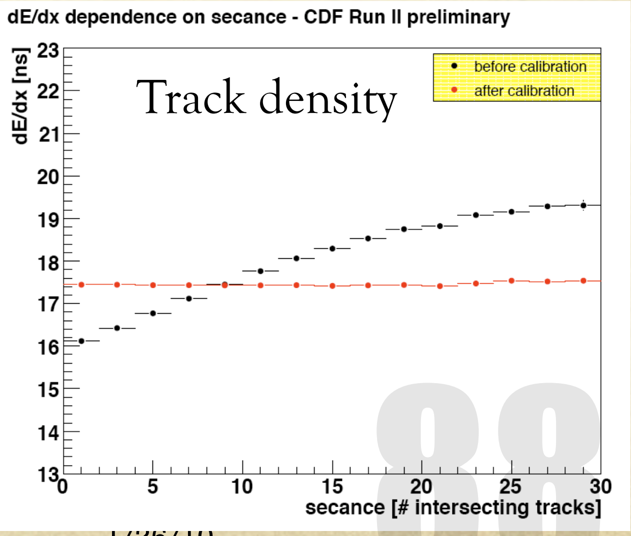






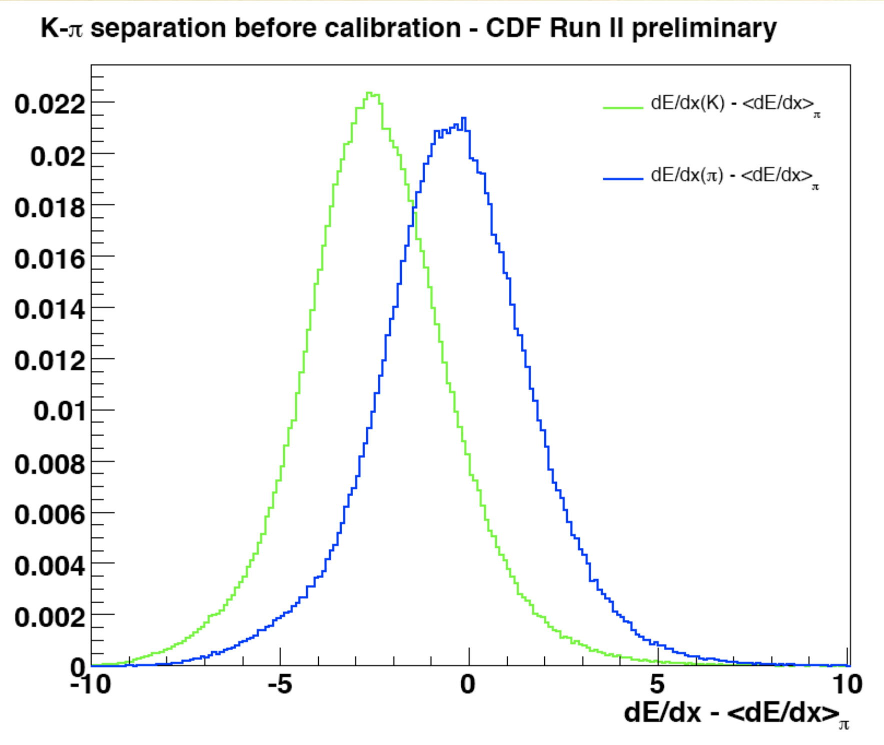




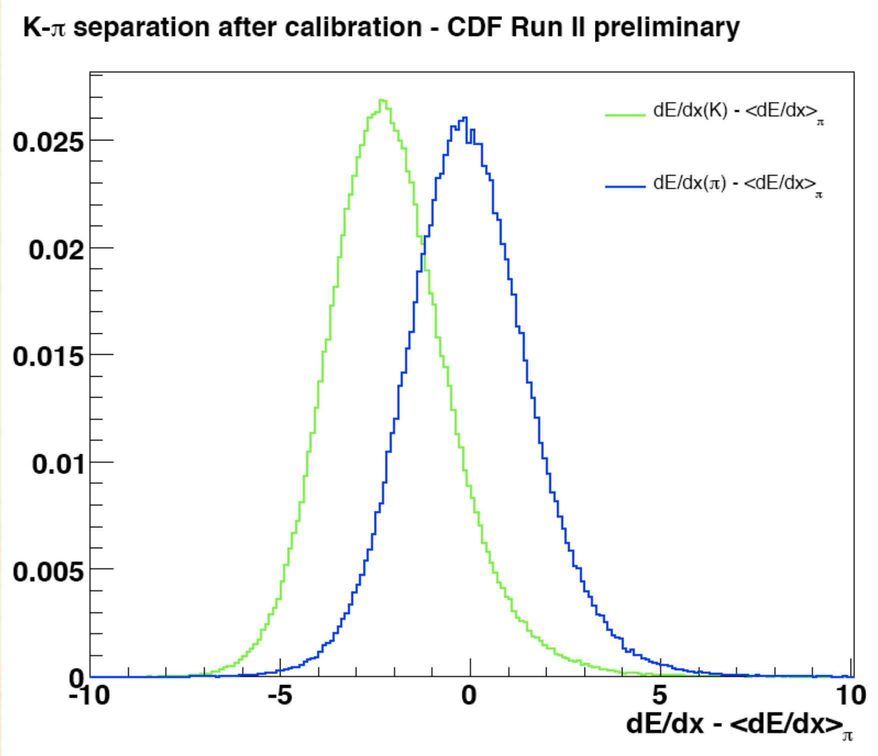


Performances

Before calibration
Separation power ~ 1σ



After calibration
Separation power ~ 1.4σ

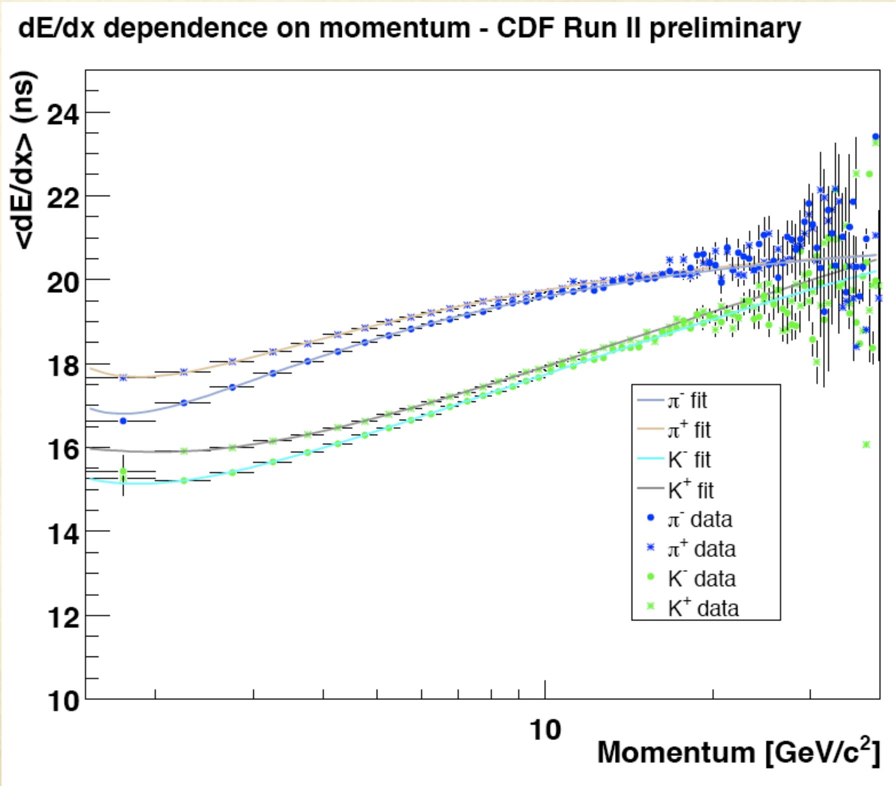


Another aim of calibration is to reduce the correlations in specific ionization between tracks in the same event. Kinematic and Environmental correlations. If large correlations are present biases will be caused in PID applications.

Universal Curves

Particle dependent predicted dEdx → CDF empirical modification of the Bethe-Bloch curve. Separate curve for positive and negative particles.

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{1}{\beta^2}\left[c_1 \ln\left(\frac{\beta\gamma}{b+\beta\gamma}\right) + c_0\right] + a_1(\beta-1) + a_2(\beta-1)^2$$



Correlations

- Another aim of calibration is to reduce the correlations in specific ionisation between tracks in the same event.
  - Kinematic correlations
  - Environmental correlations
- Correlations should be significantly reduced after corrections are applied.
- If large correlations are present biases will be caused in PID applications.

Correlations (cont'd)

Assume an uncorrected shift, c, with variance σ_c^2 affecting dE/dx of all tracks

- Define probability distribution for pion residual in pion mass hypothesis as: $\wp_\pi(\delta_\pi)$ with standard deviation σ_π
- And for kaon residual in kaon mass hypothesis: $\wp_K(\delta_K)$ with standard deviation σ_K
- If δ_π and δ_K are independent then:

$$\wp(\delta_\pi + \delta_K) = \wp_\pi(\delta_\pi) * \wp_K(\delta_K) \quad \text{and} \quad \wp(\delta_\pi - \delta_K) = \wp_\pi(\delta_\pi) * \wp_{-K}(-\delta_K)$$

$$\sigma_{\pi+K} = \sigma_{\pi-K} = \sqrt{\sigma_\pi^2 + \sigma_K^2}$$

- However, if $\wp_\pi(\delta_\pi)$ and $\wp_K(\delta_K)$ are correlated by a common mode *c:*

$$\delta_\pi^{\rm obs} = \delta_\pi + c \quad \text{and} \quad \delta_K^{\rm obs} = \delta_K + c$$

$$\wp(\delta_\pi^{\rm obs} + \delta_K^{\rm obs}) = \wp_\pi(\delta_\pi) * \wp_K(\delta_K) * \wp_c(2c) \quad \text{and} \quad \wp(\delta_\pi^{\rm obs} - \delta_K^{\rm obs}) = \wp_\pi(\delta_\pi) * \wp_{-K}(-\delta_K)$$

- In this case we can measure the variance of the unknown correlation:

$$\boxed{\sigma_c = \frac{1}{2}\sqrt{\sigma^2_{\pi+K} - \sigma^2_{\pi-K}}}$$

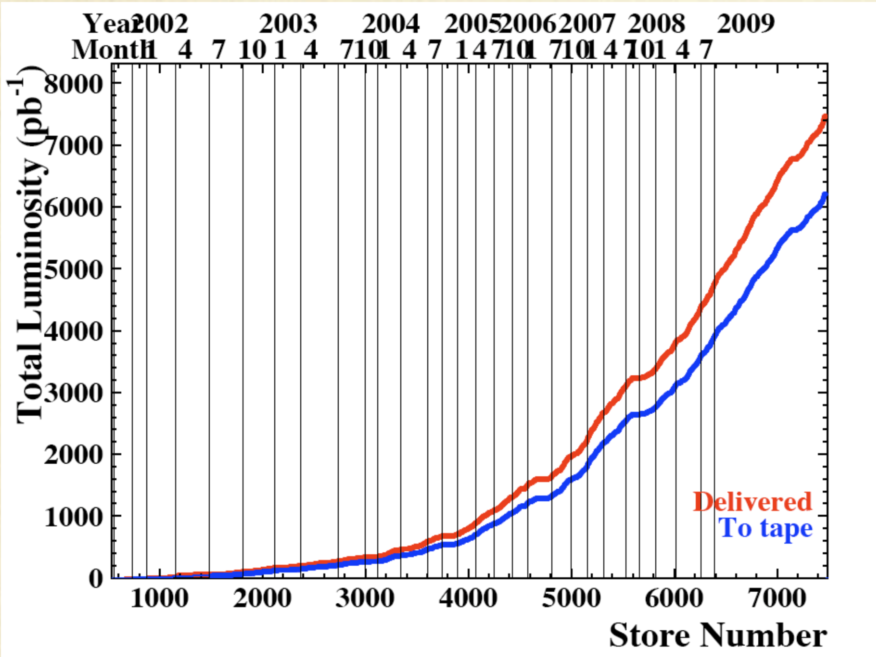
Correlations improvements

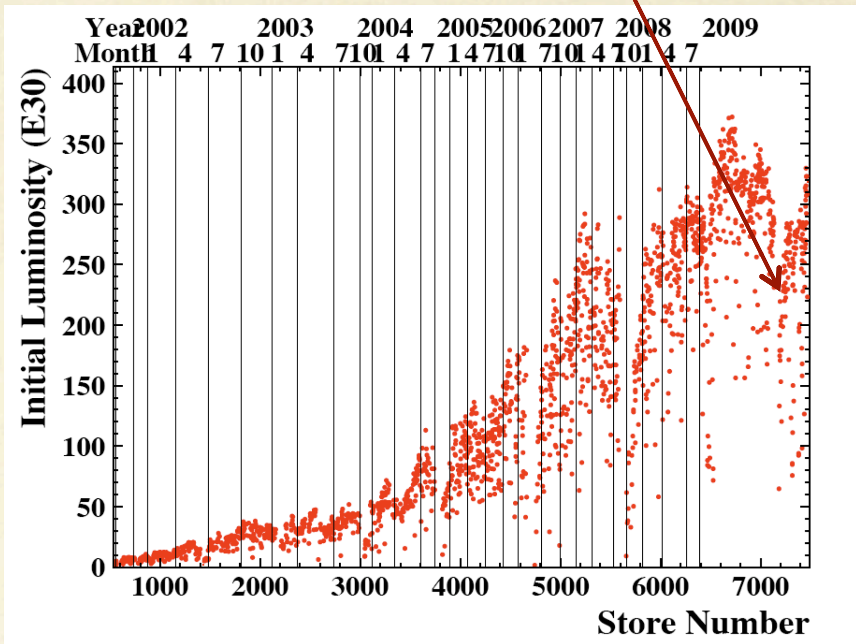
	physical event			mixed (consecutive) event		
	$\sigma_{\pi+K}$	$\sigma_{\pi-K}$	σ_C	$\sigma_{\pi+K}$	$\sigma_{\pi-K}$	σ_C
Uncorrected	**3.517**	**2.265**	**1.345**	**3.3085**	**2.528**	**1.0671**
Corrected	**2.436**	**2.253**	**0.463**	**2.386**	**2.316**	**0.285**

- Taking the pion and kaon from consecutive events should avoid kinematic correlations, leaving only environmental factors.
- Our improvements compare well with the previous calibration - reduce correlations by a factor of ~3

High luminosity

Summer 2009
shut-down





Tevatron improves continuously its performances:

Peak Luminosity regularly above 3×10^{32}

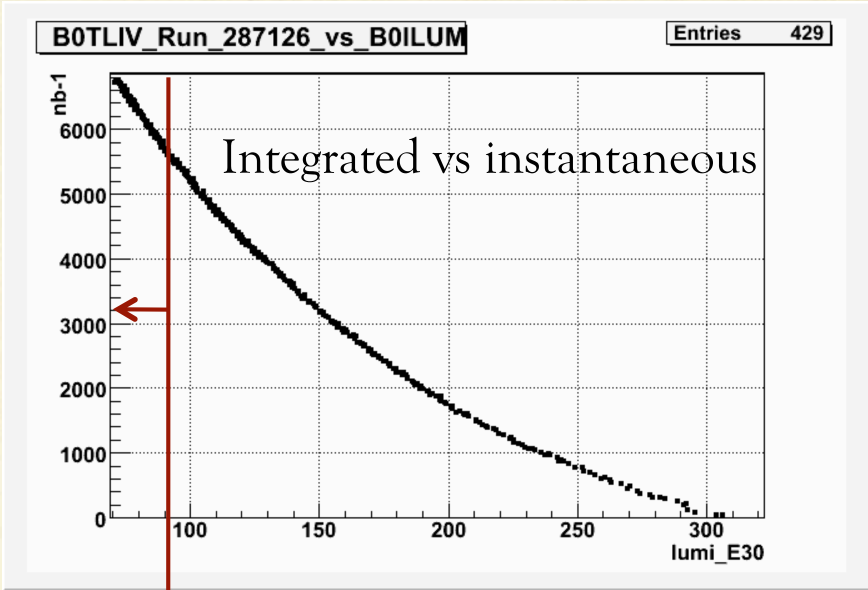
Get approximately 2 fb^{-1} per year.

Delivered almost 7 fb^{-1} and on tape about 6 fb^{-1}. Goal 10 fb^{-1} by the end of 2010.

High luminosity: hadronic trigger

L3 writes on tape at 100-120Hz
Just 10-20Hz to the Hadronic Trigger
B-Physics not the only priority ☹, Higgs ☺.

Although several trigger upgrades and stratagems (Dynamic PreScale , CLC) B-triggers suffer at high luminosities.
Yield/fb^{-1} about 50% less than in first 2fb^{-1}, but more fb^{-1} per year are integrated.



DPS =1